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EVALUATION OF ADVANCED NON-DESTRUCTIVE INSPECTION METHODS FOR A--ETC(U)
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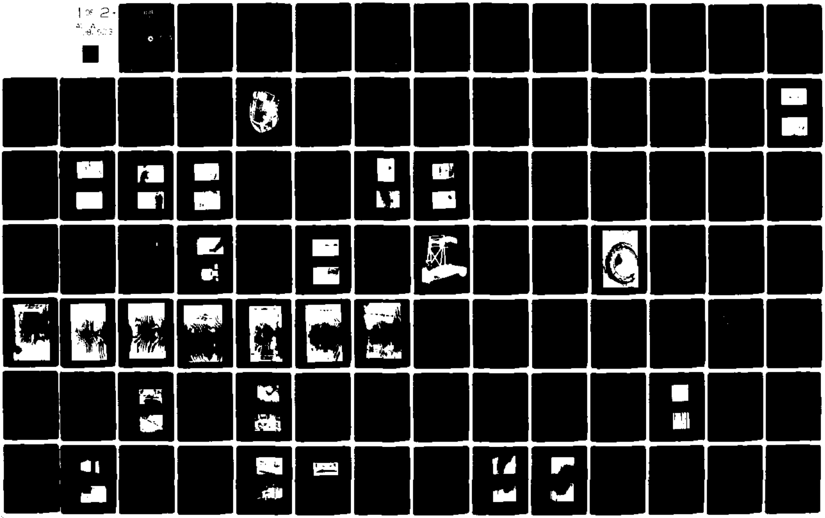

Report No. FAA-RD-80-10

LEVEL II

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EVALUATION OF ADVANCED NON-DESTRUCTIVE INSPECTION METHODS FOR AIRCRAFT TIRES

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Final Report

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16. Abstract

Advanced Non-Destructive(NDT) Aircraft Tire Inspection Systems were evaluated and compared with the air needle inspection technique normally used to qualify air carrier aircraft tires for repair, retread, and return to service. The advanced NDT inspection systems considered were: the air needle buffing, holographic, pulse-echo ultrasound, and x-ray types. A description of the equipment, inspection procedure, typical visual displays, and analysis technique is included for each inspection system. A discussion of equipment state-of-art, tradeoffs, operator skills, required manning, and inspection rates is provided. Basic equipment, installation, and maintenance costs are provided. The effectiveness of the inspection systems in detecting, identifying type and size, and locating the position of defects is reported for a group of four old defective tires and four new tires with built-in defects which were inspected by all evaluated systems. Some recent or potential advances in state-of-art are discussed.

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METRIC CONVERSION FACTORS

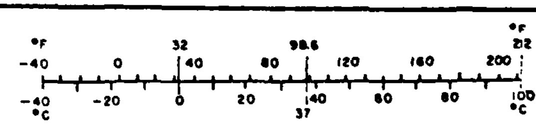
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report was prepared by The BFGoodrich Company under Contract DOT-FA78WA-4103 and describes the work accomplished under this contract. This contract was issued by the Federal Aviation Administration with R. C. McQuire of that organization serving as Contract Technical Monitor until near the end of the program when the monitorship was assumed by Mr. V. Sanborn.

The project leader was D. D. Ewing of the BFGoodrich Research and Development Center. S. J. Caprette of the same corporate facility provided major assistance in observing and evaluating ultrasonic tire inspection, making use of his knowledge and background in acoustics and sonic systems. Important contributions were made by J. R. Lindquist and D. D. Loegel of the BFGoodrich Tire Division in providing the tires for inspection and providing aircraft tire design, performance, and defect background. G. D. McQuay of the BFGoodrich Engineered Systems Division provided information on aircraft tire retread operations and inspection practice.

Important contributions were also made by tire inspection system users and vendors. These contributors are identified in the report.

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1.0 INTRODUCTION

1.1 PURPOSE

The life span of a tire for an air carrier transport aircraft is normally expected to include several tread reapplications or "retreads". Tires removed from such aircraft for wear or other conspicuous defects are subjected to inspection procedures and limiting defect criteria in order to qualify the tires for repairing, retreading, and reuse.

The purpose of this study is to evaluate advanced Non-Destructive(NDT) Aircraft Tire Inspection Systems and Criteria for qualifying such tires for repair and service by comparing them with the "air needle" inspection technique normally used for such qualification.

The end objective of this study is to identify, if possible, advanced cost-effective tire inspection methods and inspection criteria which will improve existing levels of tire performance and enhance tire operational safety.

1.2 BACKGROUND

Most tires removed from air carrier transport aircraft are removed for tread wear. A significant number of others are prematurely removed for punctures, cuts, or other damage caused by foreign objects on runways and taxiways. Others are removed because they have ruptured or exhibit conspicuous tread and ply separations, because of leakage, or because of known or suspected overheating or overloading. In any case, tires which fail in service can cause costly and unsafe damage to airframe structure and primary systems,and can jeopardize the safety of occupants. The unscheduled down time of aircraft involved in premature tire removal is also costly. It is, therefore, imperative that such tire failures be prevented or, at least, minimized.

All tires removed for wear or defects are subjected to inspection procedures and limiting defect criteria in order to qualify the tires for repairs and retreading. In most cases, external damage is detectable by a qualified inspector who can also make a judgement on the repairability of such damage. Tires not meeting inspection standards are scrapped.

The detection of internal defects or damage, such as separations between the laminated tire carcass plies or leaks in the air retention liner layer of a tire, requires a higher level of sophistication in inspection procedure. One presently used inspection method, the "Air Needle Method", pressurizes the

carcass cord ply system with air introduced through hypodermic needles inserted into the tire cord plies followed by spraying with a bubbling leak indicator fluid and careful direct visual and tactile inspection by a skilled inspector. Leaks are indicated by bubbling of the fluid in the leak area, and separations are indicated by surface bulges created by pressurization of the separated area. Other non-destructive(NDT) inspection systems for locating and evaluating internal defects are Holographic, Ultrasonic, and X-ray types.

This study is intended to evaluate these inspection systems against the air needle system and to assess the availability and cost of the systems. It is hoped that this study will indicate that one of these NDT inspection methods will be cost-effective in upgrading air carrier tire inspection by identifying and eliminating tires which may not survive another cycle of retreading and service; thereby, improving existing levels of tire performance.

1.3 PROJECT SCOPE

The advanced NDT systems and inspection criteria considered in this study included the holographic, ultrasonic, and x-ray types,and an extension of the air needle method, air needle buffing. These NDT systems were evaluated by comparing their technical features, defect detection capabilities, and costs with the air needle technique normally used to inspect air carrier aircraft tires. The principal comparison features or characteristics were:

- Effectiveness in detecting and identifying the type, size, and location within the laminate of tire defects.
- Development status of equipment and acceptance criteria.
- Purchase, installation, operating and maintenance costs.
- Operator skill and training requirements.
- Environmental and safety protection requirements.

Developers, users, and manufacturers of NDT tire inspection systems were directly contacted to determine equipment description, development status, inspection test methods,analysis methods, acceptance criteria, system costs, operator skill and training requirements, environmental and safety protection requirements, maintenance and repair requirements. Arrangements were made with several of these contacted organizations for the inspection of a group of eight(8), size 34 x 11, aircraft tires. These were 22 ply rating tires, four newly built with built-in defects and four used tires selected from rejected retread supplies as having typical service defects.

The inspection of these tires was used to compare effectiveness of the several NDT methods; and our observation of these inspections provided familiarity with equipment, test procedures, and analytical methodology.

The 34 x 11 tire size was selected because of size limitations of the sonic inspection system at DOT, Cambridge, MA. That size tire is used on the auxiliary gear(nose gear) on McDonnell-Douglas Co. DC-8 aircraft.

2.0 AIRCRAFT TIRE NOMENCLATURE

In order to clarify the descriptive nomenclature used in this report, the following definitions of the components of a typical aircraft tire construction are offered together with a cut-away view of a typical tire with corresponding component labeling (Figure 1). This nomenclature applies to both tubeless or tube type tires. The 34 x 11, 22 ply rating tires inspected as a part of this study are similar in construction to the Figure 1 tire section except for the number of carcass plies, the number of tread grooves, and the tested tires have three wire beads in each bead area instead of two as illustrated. In the size designation the first number indicates nominal outside diameter, and the second number nominal section width, all in inches. BEADS are bundles of layered steel wire imbedded in rubber then wrapped with coated fabric called BEAD FLAPS or FLIPPERS. They prevent excessive radial extension of the tire and provide a base around which the carcass plies are wrapped, anchoring the plies and providing a firm fit on the wheel. This term is also used to describe those relatively thick sections of the tire enclosing the wire beads and providing the interface with the wheel. The bead section includes a rounded inner corner known as the BEAD TOE, a rounded outer corner called the BEAD HEEL, and a radially inward facing surface, the BEAD FLAT.

The CARCASS or CORD BODY consists of layers(PLIES) of rubber-coated nylon cord. Since a layer of these cords (a ply) has all of its strength in only one direction, the cords of every succeeding ply run diagonally to each other to give balanced strength. The plies are folded around the wire beads, creating the PLY TURNUPS. The ply turnup edges are trimmed at consecutively shorter lengths to create stepped-off edges for graduated thickness change. The plies are numbered, as applied in the building process from inside to outside; i.e., the innermost cord ply is No. 1, the next ply outward is No. 2, etc.

CHAFER STRIPS or FINISH STRIPS are rubber coated fabric plies that are applied over the carcass plies in the bead and ply turnup area to protect the plies from damage when mounting or demounting the tire, minimizing the effects of chafing contact with the wheel, and also to protect against leakage.

FABRIC TREAD REINFORCEMENT sometimes called TREAD INSERTS consist of coated cord plies added to reduce tire squirm and increase stability for high speed operation. These plies are numbered from inside to outside as with carcass plies;i.e., No. 1 Insert, etc. These plies are normally buffed away and replaced in the retreading process.

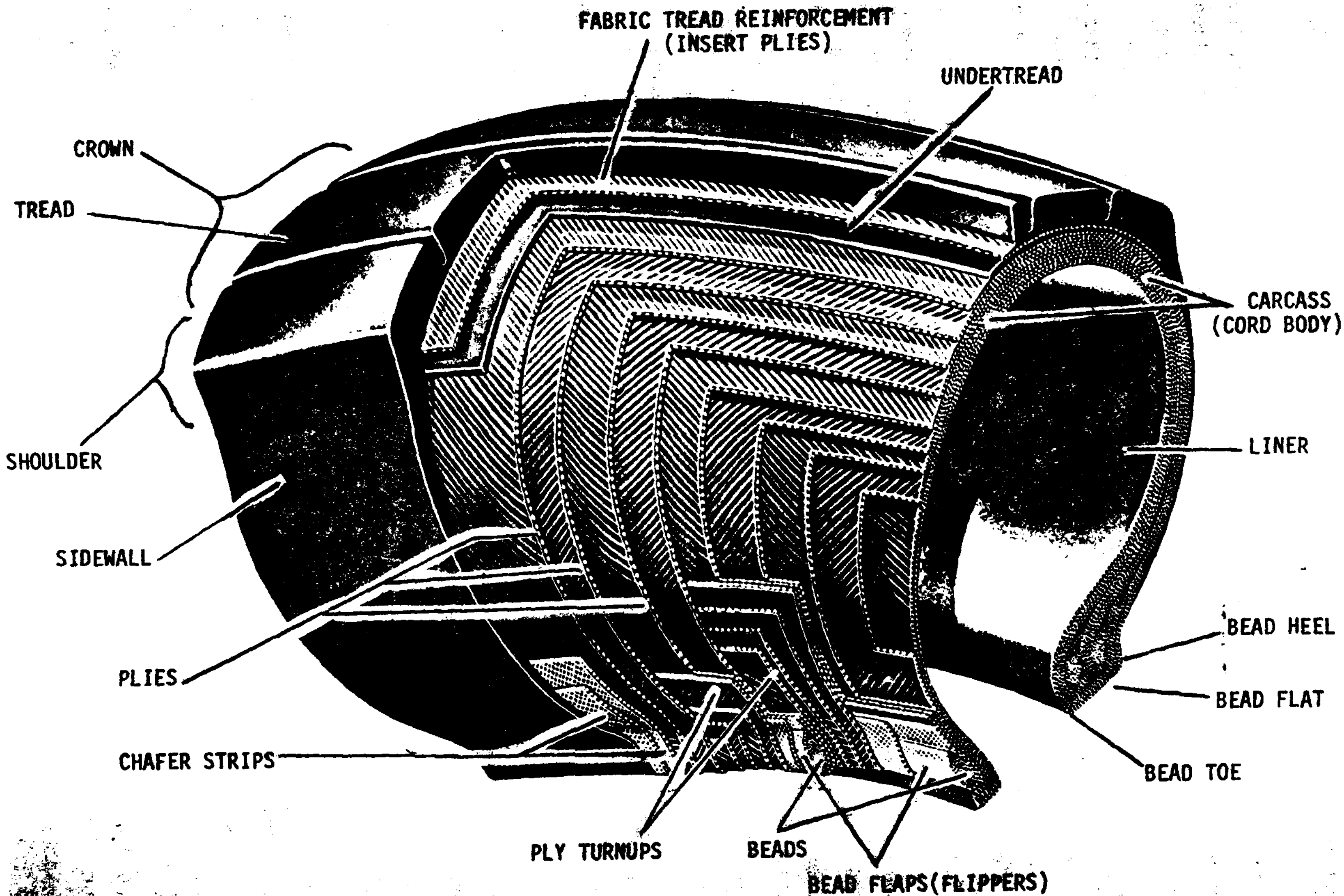


FIGURE 1. TYPICAL TIRE SECTION AND NOMENCLATURE.

The LINER in tubeless tires is a layer of rubber specially compounded to resist diffusion of air. It is vulcanized to the inside of the tire, extending from bead to bead. In tube-type tires, a thin liner is provided to prevent tube chafing.

PLY RATING identifies a given tire with its maximum recommended static load and corresponding inflation pressure when used in a specific type of service. It is an index of tire strength, and <u>does not</u> indicate the actual number of fabric cord plies in the tire carcass body.

The SHOULDER is that region of the tire section where the transition takes place from the relatively thick tread to the thinner sidewall. The side edges of the fabric tread reinforcement plies terminate in the shoulder region.

The SIDEWALL is a rubber cover over the side of the cord body to protect the cords from injury and exposure. The sidewalls may also refer to those areas of the tire between the shoulder and bead areas. The tire serial number, inflation instructions, and manufacturer's identification is usually molded into one sidewall in the form of raised or indented letters and numbers. On a dual wheel gear the serial numbered sidewall is usually mounted facing outward for easy access to the identification. In differentiating between sidewalls or sides of a tire, one is the serial side(SS) and the other is opposite serial side(OSS). When referring to rotational location of a point on a tire, a 360 degree system is used, considering the center of the serial number as 0° with the degree designation increasing in a clockwise direction when looking at the serial side of the tire. One or more raised ridges or ANNULAR RINGS may be molded on the sidewalls just outboard of the wheel flange.

The TREAD is a layer of rubber on the outer circumference of the tire, which serves as the wearing surface. With the sidewall, it helps protect the cord body from cuts, snags, bruises and moisture. The outward facing surface of the tire section between the shoulders is called the CROWN which is covered by the tread. The tread is equally spaced about a circumferential centerline called the CROWN CENTER(CC). The tread includes several circumferential TREAD GROOVES which permit escape of water during ground contact. The number and size of tread grooves may vary with tire size and different manufacturers or users.

The UNDERTREAD is a layer of special rubber which provides good adhesive qualities during retreading. The undertread separates the tread and the fabric tread reinforcement from the outermost carcass ply. During retreading, the tread rubber and the fabric tread reinforcement is buffed off and replaced in the crown and shoulder areas.

VENT HOLES are pierced through the outer sidewall rubber into the carcass plies at approximately 4 inch intervals in a circle approximately 3 inches outboard of the bead heel on both sidewalls. Care is taken not to penetrate to the liner. These vent holes permit the escape of air contained in the ply cords to prevent excessive pressurization in the plies from high pressure inflation air diffusion and air expansion during tire heat-up.

3.0 TIRE INSPECTION METHODS AND EQUIPMENT

3.1 GENERAL

Tires removed from air carrier aircraft and sent to a retread facility have been removed from the aircraft for some reason obvious to the air carrier maintenance personnel. The retreader subjects these tires to a series of inspections intended to eliminate tires containing nonrepairable defects from the expensive retreading process as early as possible and to locate and mark repairable damage or defects for appropriate action.

If a tire has been subject to severe or unusual service conditions, the nature of that service should be transmitted to the retreader for his consideration when determining the serviceability of a tire. Such unusual service should include: overheating as indicated by the blowing of thermal plugs on the wheel, over-pressurization as indicated by the blowing of wheel pressure relief plugs, or overloading as could be caused by failure or underinflation of a mating tire on a multiple tire landing gear.

The first inspection that a candidate retread tire receives is a direct visual inspection of the outer tire surfaces by a qualified inspector. If he finds no reason to reject the tire for further service, it then is given an air needle inspection which includes direct visual inspection of the inside and bead surfaces of the tire and a check for liner leakage and leakage from the bead surfaces.

After passing the air needle inspection, the tire continues to repair and retreading where it may be further inspected by one of the NDT methods discussed later and by further direct visual and air needle inspection after retreading.

Usually, as soon as the first serious nonrepairable defect is discovered, the tire is marked for scrap and further inspection may not be accomplished or recorded.

In most cases external tire damage is easily detected by a qualified inspector. However, a tire may have internal damage or strength degradation which is not detectable by direct visual or air needle inspection. The detection of internal damage is the objective sought in the more sophisticated NDT inspection systems.

An aircraft tire is a complex composite structure. The structural strength of the tire, which enables it to contain high pressure inflation air and which

produces its toroidal inflated shape, is provided by a number of plies or layers of unidirection synthetic cord fabric with successive plies oriented in opposite bias directions and with all plies wrapped around high strength wire hoops or beads which restrict radial extension and provide air sealing contact with the metal wheel. The cords in each ply and in successive plies are held in position and insulated from mutual abrasive contact by an elastomer matrix or coating which adheres to the surfaces of the ply cords.

As the tire composite is stressed by inflation loads, impact loads, and the rolling flexure produced by the flattening of the tire surface in ground contact, the tire reinforcing cords and plies are unequally stressed. Under these conditions, the cords exhibit unequal strain and relative movement which produces shear stress in the matrix rubber between cords and plies. Over a period of service there occurs a deterioration of the structural strength of the tire because of stress fatigue of the reinforcing materials and fatigue failure of the adhesive bond between matrix rubber and fabric cords. This fatigue deterioration is progressive depending on the severity of inflation stress and flexure and is accelerated by elevated temperature. These stresses are related to the number of take-offs and landings, taxi distances, aircraft weight, time between take-offs and landings, brake application history, operational weather environment, and tire inflation pressure. Locally severe stresses can be imposed by impact with foreign objects and uneven runway or taxiway surfaces or by nonuniformities in the tire structure.

This structural deterioration produces micro separations in the laminate which gradually propagate and interconnect, eventually attaining a size which can be detected by an inspection method and hopefully be used as an indicator of the degree of deterioration of the structural integrity of the tire and permit a judgement of the capability of a tire to sustain another retread and cycle of service on an aircraft.

This type of fatigue-induced deterioration is not evenly distributed throughout the tire structure because of inherent structural nonuniformities in the tire and because flexure tends to be more severe in some areas, notably the shoulders and at the edges of ply turnups.

Separations which occur between the first ply and the elastomer air retention layer on the inside tire surface, are accessable and repairable. Likewise, separations which occur outboard of the outer tire carcass ply in the tread or shoulder areas are accessable for repair or will be buffed away and replaced during the retreading process. Such separations need not be reasons for disqualifying a

tire for retreading, unless they are so numerous that they are regarded as an indicator of excessive tire degradation.

The NDT tire inspection systems, in order to upgrade retread tire performance, should be able to detect excessive tire deterioration as evidenced by separations of critical size in the tire laminate, and should be able to detect localized critical damage as indicated by separations or broken ply cords. It was not expected that the advanced NDT inspection systems evaluated in this study would be capable of providing leak detection as does the air needle system,nor was it expected that direct visual inspection would be eliminated.

In evaluating NDT systems one of the problems which must be considered is: what is the critical size of a separation, or what size separation must be detected? Discussions with BFGoodrich tire service and design personnel indicated that detection of separations as small as 1/4 inch diameter would be desirable. It was generally agreed that service fatigue degradation in a tire produces tiny separations which gradually enlarge with further service fatigue until they reach some critical size when the rate of enlargement or propagation increases markedly - probably exponentially - eventually leading to tire failure. This propagation rate is probably more rapid in tire areas, such as the shoulders, which are subject to severe flexure. Therefore, the critical size of separations is probably smaller in the shoulder area than in the tread center area where less flexing takes place.

It was decided that the four new tires,specially built for the NDT inspection evaluation, should include separations or unbonds of 1/4 inch, 1/2 inch, and 1 inch diameters. Such separations would be induced in different areas of the tire section and some of each should be located between two inner plies, between two middle plies, and between two outer plies. These separations or unbonded spots were to be created by inserting disks of plastic release film(1 mil Mylar) in selected areas during the tire building process.

These tires would be subjected to several dynamometer take-off cycles before testing to provide flexure of the tire to break loose any surface adhesion to the plastic release film to assure that separations existed,and to flex the cord plies to enhance air migration between the plies during air needle inspection.

The inclusion of four used tires with service-induced defects and separations in the NDT inspection would provide an indication that the NDT method was indeed detecting a separation and not just the plastic release film.

It was suspected that air needle inspection could cause some growth of separations; so, we would attempt to have the tires inspected twice by each test method. The first round of inspections by each method would be done before the new tires were air needle inspected. Then, all tires would be air needle inspected; and again, all tires would be reinspected by the other NDT methods.

The air needle buffing NDT method was not originally planned in the program. This method was done only once after all other testing was complete.

Two inspection sources of the eight test tires by each of the other advanced NDT inspection methods were sought. We only located a single source for the ultrasonic testing, and we encountered some scheduling difficulties with inspection by equipment manufacturers and users. Tire inspection equipment is manufactured to order, and the manufacturers do not keep demonstration equipment on hand. We had to schedule inspections on x-ray equipment when it was assembled for check-out in the shop. One holographic manufacturer borrowed a customer's equipment to perform inspections on our tires.

Following is a description of each NDT inspection method including the information and inspection sources, equipment descriptions, inspection and analysis methods with typical visual display photographs, and discussion of the other comparison features.

3.2 AIR NEEDLE INSPECTION METHOD

3.2.1 GENERAL

The air needle inspection methodology and the relatively simple equipment utilized is based on current practice at BFGoodrich Aircraft Tire Retread Centers and is representative of that used throughout the industry; although there may be minor differences in procedure or equipment detail.

Aircraft tires are normally inspected by the air needle method twice during each retread. The first inspection is done after direct visual inspection before any repair or retread work is done on the tire. This first inspection is a search for leaks and other defects on the liner and bead surfaces of a tire. Repairable defects are marked on the tire surface to aid repairmen in their location, and also noted on a travel card or record sheet which accompanies the tire throughout its repair and retread process. The second inspection is done after repair and retread cure to make sure there are no leaks or other defects and to check vent hole function before the tire returns to service.

3.2.2 INFORMATION AND INSPECTION SOURCES

Air needle inspections were actually performed twice on the lot of eight 34 x 11 sample tires during this evaluation study. Once in the Akron, Ohio plant facility after the tires had been inspected by the x-ray, holographic, and ultrasonic methods; and again at the Montreal, Quebec, Aviation Products Service Center prior to the final, air needle buffing inspection. The latter was then used as the basis for comparison with the other methods since it included the inspection of some damage to the tires which had occurred during shipment of the tires between inspection sites.

3.2.3 EQUIPMENT FOR AIR NEEDLE METHOD

The equipment needs for this method are relatively unsophisticated and can be adapted to available space.

The tires must be supported in an upright position to provide access to both sidewalls for needle insertion and to prevent loosening the needles during the 15 to 30 minute pressurized soak or preconditioning. Pipe or tubing racks of various designs serve nicely. Two rack designs are shown in Figures 3 and 8. A piping system to deliver 125 psig air to each rack position must be provided. The air supply should include a good quality regulator and gage to adjust and monitor air pressure. The air should be filtered to remove dirt, oil, and moisture. The supply should be adequate to accommodate the flow out of the needles for the number of tire positions provided. Two needle positions must be provided for each tire position in the racks. Shut off valves or self-actuating check valve quick disconnects should be provided for each needle. The needles are mounted at the ends of flexible tubing or hoses on adapter handles which can be purchased from a tire equipment supplier. Needles are short(1/2 inch to 3/4 inch long) 15 to 16 gauge hypodermic needles(approximately .050 inch I.D.) with length selected to prevent penetration to the tire liner when inserted. See Figures 3, 7, and 8.

An air spray gun is provided for application of a leak indicator solution from a 55 gallon drum or 5 gallon bucket reservoir. Commercial leak indicator solutions are available or soap solutions can be used. See Figures 4 and 5.

An inspection lift is usually provided, Figures 4 and 5 . This is a fork lift type device with rollers serving as forks, which can lift the tire to a convenient elevation for visual inspection and permits rotating the tire on the rollers.

A portable light for inspection and a clock or timers for timing the pressure soak time are needed.

3.2.4 <u>COST OF EQUIPMENT</u>

The cost of an air needle inspection station, including all equipment described above, is estimated at $2500. One station would equip one inspector to handle 75 to 100 tires in an eight hour shift. A second station and inspector would probably be required to perform inspections after retreading.

No special or unusual environmental requirements or personnel safety requirements are posed by this equipment. High pressure air and electric power are required for other retread processes and are not needed solely for this equipment.

3.2.5 <u>INSPECTION PROCEDURE</u>

Candidate retread tires are usually sorted by size and by the airline which returned them. They are then given a careful direct visual inspection, Figure 2, with repairable damage or defects marked on the tire surfaces and noted on a travel card which accompanies the tires through the retread process and which becomes part of a record maintained on the tires' retread and service history. The tires deemed acceptable during this inspection then proceed to an air needle inspection. The tires are then placed in upright position in air needle test racks. Two air needles are inserted, one in each sidewall and approximately diametrically opposite in location. The needles are inserted at a 45° angle to the sidewall surface with the needle points outward(away from the beads) in the ply turnup region(just outboard of the annular rings) so the needles penetrate into the carcass plies. Needle length should be selected to prevent penetration to the liner,which could cause a liner leak. The air supply is turned on and checked to be 125 psig and the start time of pressurization of each tire is noted. This procedure is repeated for all tires in the racks, Figure 3.

After approximately 15 minutes of pressurization, the needles are removed from a tire and it is immediately placed on the inspection lift. One needle is then inserted into a sidewall of the tire and connected to the pressure supply. The vent holes on the tire are sprayed with leak indicator solution, Figure 4, and the tire is observed to make sure the vent holes are leaking - an indication that the air pressure has migrated throughout the carcass. If vent

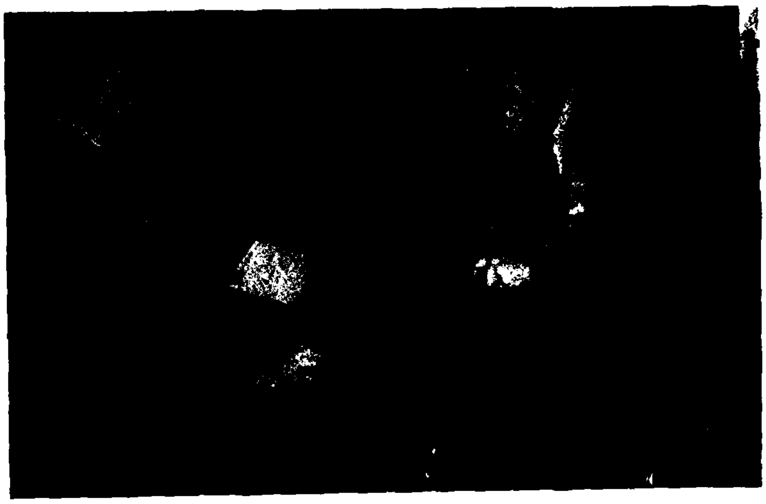


FIGURE 2. DIRECT VISUAL INSPECTION.

FIGURE 3. TIRES IN AIR NEEDLE INJECTION RACK.

hole bleeding is not visible, the tire is returned to the rack and air injected for an additional 15 minutes.

If the vent holes are bleeding normally, the leak detector solution is sprayed on the inside of the tire and both bead areas, Figure 5. The entire surface of the liner and beads is visually checked for leaks. Leaks are marked by circling with crayon for location by repairmen. Leaks are gently probed with an awl to determine if cord breakage is associated with the leak.

The entire liner and bead surface is visually inspected for surface bulges which are highlighted by the wetting of the leak indicator solution, Figure 6. Bulges are also sought by lightly rubbing the fingertips over the beads and the lower inner and outer sidewall, the fingertips being very senstiive to surface irregularities. Located bulges are gently depressed or probed with an awl to determine the depth of the separation in the laminate. If any cord ply separation is involved the bulge is marked and the tire rejected. Small isolated bulges of only the liner may be repairable by patching.

Excess leak detector solution is siphoned or wiped from the tire by sponge or rags.

Any leaking or loose edged patches or balance pads should be removed prior to or during air needle inspection.

Inspection results are noted on the travel cards accompanying the tires and tires are forwarded to a drying room prior to repair and retreading unless they are rejected.

Occasionally, if a separation is suspected near the outer carcass surface (as may be detected during the buffing off of the old tread rubber) a tire may be air injected after buffing to make such a separation bulge outward to assist detection, Figure 7.

After a retreaded tire is vulcanized and trimmed, it is rechecked by air needle inspection to verify that there are no liner or bead surface leaks, to verify the integrity of repairs, to verify vent hole function, and to make sure no new separations have occurred during retreading before it is returned to service. Any defects detected would be cause to return the tire to the appropriate repair station for correction. Figure 8 shows retreaded tires in a rack being air injected and Figure 9 shows such a tire with sprayed leak detector bubbling at vent hole sites.

FIGURE 4. SPRAYING BEAD AND VENT HOLE AREA.

FIGURE 5. SPRAYING INSIDE OF TIRE ON INSPECTION LIFT.

FIGURE 6. VISUAL INSPECTION OF THE INSIDE TIRE SURFACE.

FIGURE 7. AIR INJECTION AFTER BUFFING TO INSPECT FOR OUTER SURFACE SEPARATIONS.

FIGURE 8. RETREADED TIRES IN AIR INJECTION RACK.

FIGURE 9. LEAK INDICATOR BUBBLES AT VENT HOLES ON AIR INJECTED TIRE.

3.3 AIR NEEDLE BUFFING METHOD

3.3.1 GENERAL

The air needle buffing method for NDT inspection of aircraft tires was included in this evaluation after all other evaluation testing was completed. This method has been successful at the BFGoodrich Aviation Products Service Center(retread center) in Montreal,Quebec in detecting separations in aircraft tires for Canadian airlines. It has always been intended for use in conjunction with conventional air needle inspection as described in the preceding report section, 3.2. This includes buffing off the old tread rubber and the tread reinforcement plies, so it was necessarily performed on the eight 34 x 11 test tires only once and after the other methods had been utilized.

3.3.2 INFORMATION AND INSPECTION SOURCES

Information on this method was provided by Mr. Gordon D. McQuay of BFGoodrich, Akron, Ohio and by Mr. Swee Foo Lim of BFGoodrich, Montreal, Quebec. The actual inspection was performed by Mr. Lim at the Montreal retread facility.

3.3.3 EQUIPMENT FOR AIR NEEDLE BUFFING

This inspection method requires a relatively simple adaptation and modification of commercial buffing equipment to provide the air needle injection capability during the normal buffing operation. The tire buffing machine used in this case was a BUFF-O-MATIC™, a trademark of the National Standard Company, Rawls Division, Lima, Ohio. This buffer includes an expanding flanged rim on which the tire bead seats while the tire is inflated with low pressure(30 psig) air to accomplish a bead seal and to round and firm the tire for buffing. The rim expansion is accomplished via radial cams actuated by an air cylinder supplied with 125 psig air. Tire, rim, and air cylinder are fixed together during buffing and all rotate together. The rim actuating cylinder thereby provides an air source which rotates with the tire and which can be tapped to supply pressure to air needles at the correct pressure. A small 1/4 inch pipe threaded hole is drilled and tapped near the machine end of the air cylinder and a check valve quick disconnect for hose is installed on an elbow. The machine half of the disconnect is sealed by the check valve when the other half of the disconnect is disengaged and is opened by engagement of the disconnect. Several commercial varieties of such disconnects are available. The male disconnect half is attached to a length of air hose through a pipe street elbow and a tee as shown in Figure 10. A second hose is attached to the tee. Short hypodermic needle adapters are attached to the hose ends. The hose lengths are adjusted so the short hose permits reaching the machine-facing tire sidewall with minimum slack and the

long hose extends through the openings of the spoke-like cams of the expandable rim to the outside tire sidewall with minimum hose slack. Figure 10 shows the hose assembly laying on a buffed tire with the machine half of the hose disconnect near the bottom of the air cylinder hub. Figure 11 shows the hose assembly connected with air needles inserted in a tire. Figure 12 shows the machine-side hose with needle inserted and Figure 13 shows the outward tire sidewall with needle inserted.

Short needle adapters and appropriate hose lengths minimize the centrifugal forces which could tend to dislodge the needles when the tire rotates during buffing. Hose assemblies of different lengths can be provided for different tire sizes. Different tire sizes also require different expandable rims which attach over the rotating air cylinder.

Another rubber hose can be seen in Figures 10, 11, and 12, connected just to the right of the air cylinder. This hose connects to a tire valve in the expandable rim to provide tire inflation pressure at approximately 30 psig. This is part of the standard buffer system and is not part of the air needle adaptation.

3.3.4 COST OF EQUIPMENT

The cost of the simple machine adaptation and three different size hose assemblies is estimated at $200 for each buffing machine.

This method adds approximately five minutes to the normal buffing operation. This time is devoted to insertion and removal of the needles, occasional slowing and stopping of the tire rotation and buffing operation to inspect suspected separation areas, allowing the pressure to bleed down in the tire carcass while the tire remains on the machine and rotates slowly for surface inspection, and marking located defects and noting them on the travel card record for the tire.

It is also necessary to train the buffing machine operator in recognizing defects - primarily separations - revealed by this method.

No special environmental or safety hazards are added to the buffing operation.

3.3.5 AIR NEEDLE BUFFING INSPECTION PROCEDURE

Tires to be inspected by the air needle buffing method would have already passed through a direct visual outside surface inspection and an air needle inspection as described in the preceding report section, 3.2. The tires would be sorted by size and appropriate expandable rim and buffing profile cam installed on the buffing machine. An appropriate length hose assembly for air needle injection would also be selected.

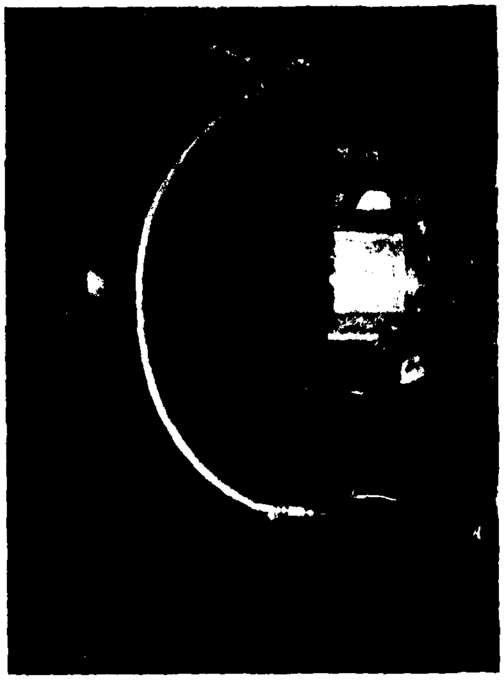


FIGURE 10. HOSE ASSEMBLY FOR AIR NEEDLE BUFFING AND HOSE DISCONNECT ON AIR CYLINDER HUB.

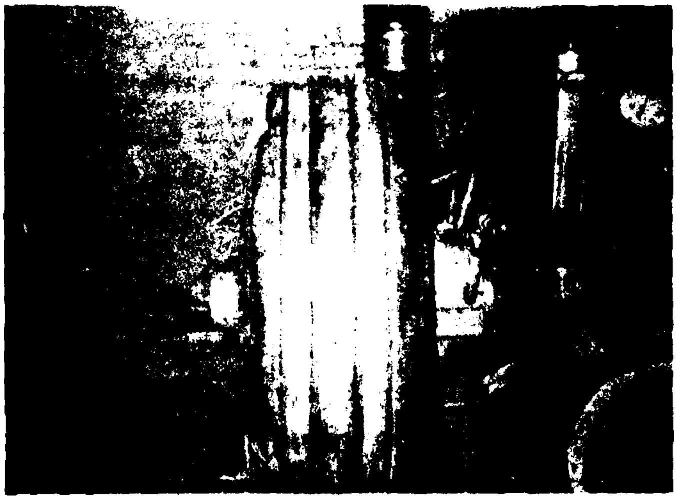


FIGURE 11. HOSE ASSEMBLY CONNECTED WITH NEEDLES INSERTED IN TIRE SIDEWALLS.

FIGURE 12. HOSE ASSEMBLY CONNECTED FOR AIR NEEDLE BUFFING.

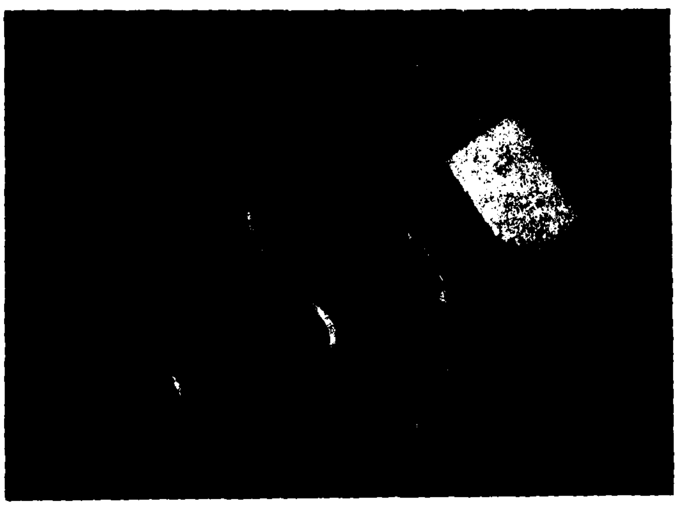


FIGURE 13. OUTER SIDEWALL VIEW WITH AIR NEEDLE INSERTED.

The tire is lifted onto the expandable rim, the rim is expanded by introduction of air pressure, and the tire is air inflated to force the beads outward against the rim flanges and to firm up the tire to its inflated shape. The tire is rotated while it is observed for uniform rotational alignment. Wobbly rotation is an indication of improper seating of the bead against the flanges of the expandable rim or of distorted beads which is cause for scrapping. When uniform rotation is observed, the tire is stopped for air needle insertion.

The air needle hose assembly is positioned with disconnect valves near engaged position, the long needle supply hose extended between rim cams to the outside of the tire, and inside hose near its insertion position. The hoses can be slightly wrapped around the air cylinder hub to take up hose slack to reduce outward throw of the hose during tire buffing rotation. The air needles are inserted into the carcass as during air injection described in report section 3.2.5. When the needles are in place the hose disconnect is engaged, opening the disconnect check valve, and air is supplied to the needles. The tire is slowly rotated to check needle hose positions for adequate clearance while rotating.

The buffing operation is started in normal manner. As the heavy tread and shoulder rubber, and tread reinforcement plies are buffed off, underlying separations may become apparent on the buffed surface as outward bulges which are no longer suppressed by the heavy outer rubber. The buffing machine operator observes the buffed surface continually for such separation evidence and may stop the tire rotation for closer inspection. Separations are marked on the tire surface where located.

If there is doubt about the depth in the laminate of a separation, the buffing would be continued to its normal depth; i.e., until the entire tread, tread reinforcement ply, and approximatley half of the undertread rubber is removed. Separations which are outboard of the carcass are probably completely buffed away. Remaining separation bulges can be gently probed with an awl to determine if any carcass ply separation is involved. Carcass ply separation is cause for disqualifying the tire for retread. Isolated separations between outer carcass ply and undertread rubber may be repairable.

After completion of buffing to normal depth, the tire can be rotated slowly to check for bulges or other defects and then stopped for disengagement of the air needle hose disconnect, permitting the carcass injection air pressure to subside. After approximately two minutes the tire is again slowly rotated while the buffed surface is observed. Small separations which may have been overlooked in their inflated bulge condition may then be observed as slight depressions in the bulged

surface,since more rubber is buffed off the bulged surface. Such depressions usually exhibit subtle color difference in concentric ring patterns around the depressions where different rubber layer edges are exposed in the depression.

Carcass ply separations which bulge significantly may appear as bare cord fabric spots where all the overlaying rubber was buffed off.

Located separations are marked on the tire surface by circling with chalk as shown on the buffed tire in Figure 10.

Notation of defects description is made on the tire travel card and appropriate disposition is made of the tire.

At the conclusion of this recording the air needles are removed from the tire, it is demounted,and the next tire is similarly mounted for buffing and inspection.

3.4 HOLOGRAPHIC INSPECTION METHOD

3.4.1 GENERAL

Of the advanced NDT tire inspection systems evaluated during this program, the holographic system had already gained the widest application and acceptance for aircraft tire retread qualification inspection.

This system utilizes a photographic technique to detect relative distortion of the surface of a tire in a stressed condition as compared to the surface position in an unstressed condition. The stress is applied by enclosing the tire in a vacuum environment of controlled magnitude. Defects influence surface distortion in detectably characteristic manner. Too much stress(vacuum) may induce too much surface distortion which may inhibit defect detection. The photographic plate or film is double exposed with one exposure in each the stressed and unstressed condition; therefore, the tire surface being photographed must be maintained in the same respective position to the camera for both exposures. Either the inside tire surface or the outside tire surface can be photographed; although,the thick rubber of the tire tread and shoulders tends to diminish surface distortion in that tire area caused by the stress of expanding gas within the tire carcass when enclosed in a partial vacuum.

Since the tire is a complex shape, the camera can "see" only a portion of its surface for each set of photographs. To make this system practical for inspecting tires it is necessary to minimize the number of photographs,and to devise a means for positioning the tire accurately with respect to the camera and light source to make a succession of photographs encompassing the surface areas to be inspected.

The tire/camera positioning systems in use on current holographic inspection systems spread the tire to make its inner surface more visible when the tire rests on one sidewall with the camera located at the rotational axis of the tire. The inside surface of the tire is photographed by either rotating the tire about the camera or by rotating the camera.

The sidewalls of a spread tire are significantly foreshortened in the resulting photographs, if they can be seen at all. Aircraft tires, because of their many-plied carcass construction and the resulting carcass section stiffness, generally cannot be spread far enough, without permanent bead distortion,to photograph the lower sidewalls. Mirrors can be used to photograph lower sidewalls or the tire beads may be pinched together to photograph the outer sidewalls; but these techniques leave much to be desired in terms of cost and distorted imagery.

The holographic inspection of aircraft tires has, therefore, been confined to that part of the inside tire surface exposed by spreading the tire beads. This includes the crown, shoulders, and upper sidewalls. In spite of these limitations, this method has been used with sufficient success to gain fairly wide acceptance.

3.4.2 SOURCES OF INSPECTION AND INFORMATION

An attempt was made to obtain two sources of holographic inspection for the test tires in this evaluation study. It was decided, as a matter of convenience, to use the inspection facility at BFGoodrich, Akron,Ohio as one of these sources. This BFGoodrich facility consists of a late Model K-160 system manufactured by Industrial Holographics, Incorporated(IHI), Auburn Heights, Michigan. Because of this in-house availability of IHI equipment, another source using other equipment was sought.

IHI was contacted as a source of information on equipment, state-of-the-art, pricing, and future developments. The acceptance that holographic equipment enjoys in the tire inspection field is probably attributable to the capability, energy, and enthusiasm of IHI President, Dr. Ralph M. Grant. Dr. Grant and Mr. T.R. Zimmerman, Director of Engineering at IHI, were most helpful in providing information.

Newport Research Corporation(NRC), Fountain Valley, California, provided the second holographic inspection source. NRC did not have a holographic tire inspection system in-house but they made arrangements to use a customer's test facility at an army base in Yuma, Arizona. The equipment used was identified as a Model AT-12 Holographic Tire Analyzer of NRC/GCO design. The actual holographing of the test tires was done by Mr. Dennis Terry, an engineer at NRC. The analysis, equipment description and cost information was provided by Mr. J. T. Thomasson, Director, Industrial Systems Division, NRC.

At BFGoodrich, Mr. C. M. Hoff, Senior Tire Development Engineer, who has the engineering responsibility for the Akron, Ohio holographic tire inspection facility, provided the analysis of the inspected test tires and provided much useful information on the capabilities of that system.

Some published papers on the holographic inspection of ground vehicle and aircraft tires were located. The most significant of these papers were prepared for Symposia on Nondestructive Testing Of Tires sponsored by Army Materials and Mechanics Research Center, Watertown, Massachusetts, and published in the proceedings of those symposia and available through the National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, Virginia 22161. Specific papers are listed as References 1, 2 , 3 , 4 ,and 5.

3.4.3 DESCRIPTION OF EQUIPMENT FOR HOLOGRAPHIC SYSTEM

Holography is a process of three-dimensional photography. Figure 14 schematically shows the setup to record an image on a photographic media that can be displayed in three dimensions. A coherent or single frequency light is used. As shown in Figure 14, a laser is used for this single frequency light,and it is split into two distinct paths. One path, called the object beam, is used to illuminate the object and is reflected back from the object to the film plane. The second path, called the reference beam, is brought directly onto the film plane by a system of mirrors. It is the interference of the reflected light wave coming from the object and the light wave from the reference beam that creates an interference pattern that is recorded on the film producing a "hologram". When the developed positive film transparency is illuminated by a light source similar to the original reference beam, the object will be reconstructed in three dimensions in the view of an observer. Figure 15 demonstrates this reconstruction.

By using a double exposure holographic technique, an interferometer can be constructed to measure very small movements of the object when it is stressed. Figure 14 demonstrates this basic principle. If the object is holographed when it is at a steady state condition, and a second holograph is taken on the same film frame after the object is stressed, causing its surface to move to a different position as shown by the dotted line, this small movement will change the length of the reflected light path. The difference in optical path length creates a series of interference fringe lines on the hologram as shown. If the surface of the stressed object has moved uniformly toward the film plane, the interference fringes are horizontal and uniform. These are indicated as background fringe on the image of Figure 14. If the object contains a structural nonunformity which restricts or accentuates local surface movement when stressed, it will cause local aberrations in the fringe recorded on the hologram.

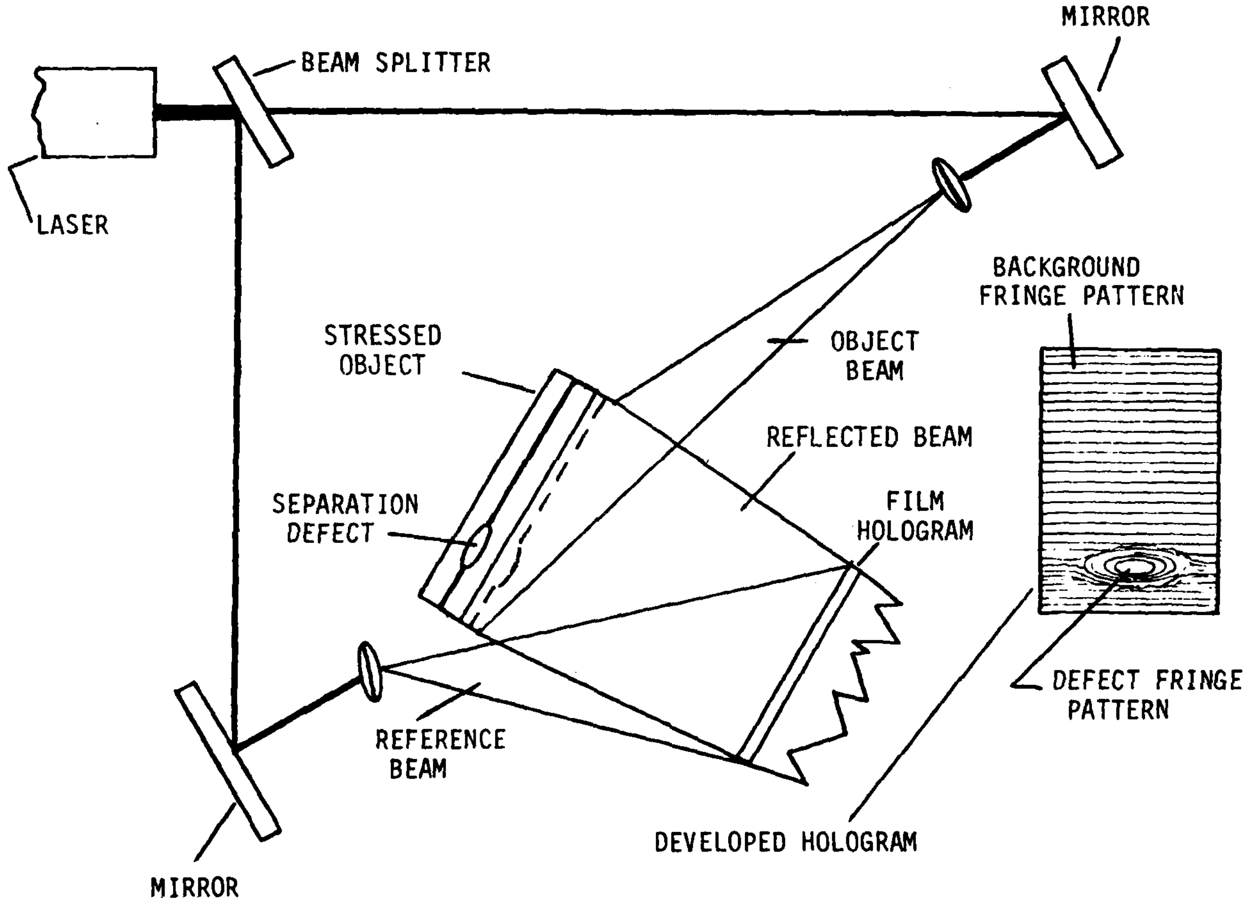


FIGURE 14. HOLOGRAPHIC INTERFEROMETRY WITH BACKGROUND AND DEFECT FRINGE PATTERN SHOWN.

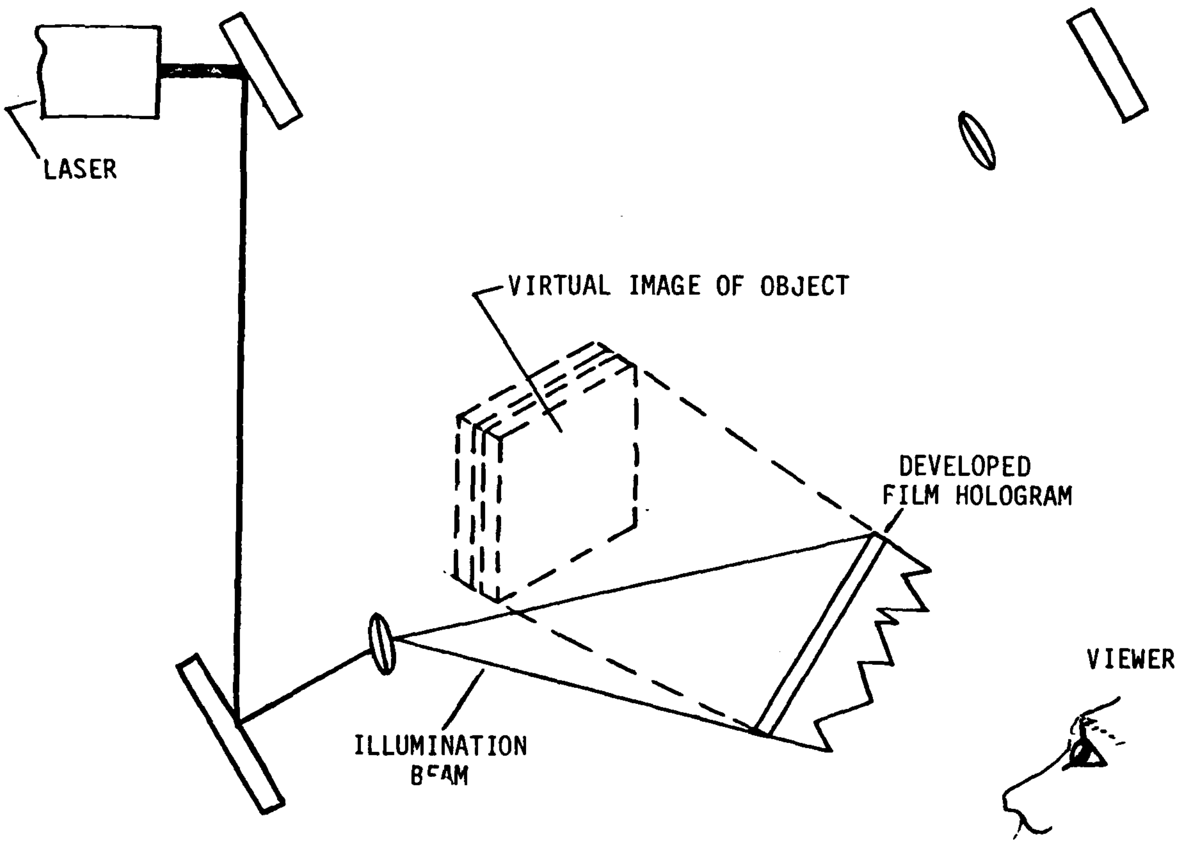


FIGURE 15. RECREATED IMAGE OF OBJECT BY LASER ILLUMINATION OF HOLOGRAM.

When holographing the surface of a tire, the first photographic exposure is accomplished with the tire at ambient atmospheric pressure. A vacuum environment is then induced about the tire without moving the tire with respect to the camera. Capillaries in the cord plies of a tire and the micropores in the rubber contain air as would any separated or unbonded region in the tire laminate. The quickly induced surrounding vacuum allows expansion of this air, causing swelling of the tire and small movement of the tire surface toward the camera. A separation defect would permit local increased surface movement or bulging. A second photographic exposure in this vacuum-induced stress condition produces a hologram with distorted fringe lines in the local defect areas as shown in Figure 14. Different types of structural defects produce characteristic aberrations of the background fringe lines. By learning to recognize the characteristic fringe aberrations, the location, type, and size of structural defects can be deduced upon viewing the illuminated hologram.

The number of fringe lines that appear on a hologram is a function of the wave length of the coherent light source used during photography and the amount of object surface deformation which, in turn, is proportional to the applied stress or vacuum. Too much vacuum can produce too many fringe lines which may make defect detection more difficult. For the laser light sources evaluated in this program, a fringe line is produced in the area of a separation induced bulge, for each 13 millionths of an inch(.000013 inch) of bulge height. This indicates the sensitivity of the system to minute surface movement, and suggests the need to isolate the tire-camera-light source system from transient vibrations from the environment.

The steeper the sides of a surface bulge, the closer will be the fringe lines on the hologram. The total number of fringe lines depends on the total bulge height.

In the case of a bulge resulting from a separation, the closer the bulge is to the photographed surface, the steeper its slope tends to be. A count of the fringe lines in the bulge area is an indication of the depth of the separation in the laminate. If the bulge is small (1 inch diameter or less) and the fringes are numerous, the ability to count the fringes depends on the quality of the photography and of the viewing system. The photographic quality depends on camera aperture and lens speed and available light. Available light can be a problem depending on laser power and the reflective qualities of the tire surface, which is poor at best. A coating or dusting of the tire surface with a reflective material such as talc can enhance the photograph quality.

The recommendations of equipment manufacturers together with some experimentation enables the establishment of effective photographic procedures and vacuum levels for tires of different sizes and manufacturers.

The holographic equipment used at BFGoodrich, Akron, Ohio, is a late Model K160 Holographic Tire Analyzer manufactured by IHI. This model, or equivalent, is regarded as the basic equipment needed to accomplish inspection of aircraft tires. The basic equipment components and size envelopes are described on Figure 16. A number of equipment options are available to supplement the basic equipment.

The Model K160 Tire Analyzer is capable of inspecting tires of maximum weight of 500 lbs. with bead diameters between 10 and 32 inches, and maximum outside diameters of 56 inches. The major components of the system are:

- A test platform or base, supported on pneumatic vibration isolation mounts, including a circular turntable on which the tire is placed for inspection. The laser and the interferometer are mounted on the base to maintain a fixed spacial relationship with a tire which is placed on the turntable. Thus, all elements involved in the photographic process are uniformly vibration isolated on the massive base.
- A Krypton-ion laser is supported in a housed cradle at one side of the base.
- A remote laser power supply and a remote closed loop water cooler are provided in a cabinet.
- A vacuum chamber dome raised and lowered by a pneumatic lift system. The dome encloses the turntable and tire, seating on the base to complete the vacuum enclosure. The lift is uncoupled from the dome after lowering to prevent vibration transmission.
- A remote vacuum supply cabinet.
- The interferometer optics and camera mounted at the center of the turntable. Figure 17 shows the interferometer and turntable. The camera film is contained in a magazine providing sufficient film for approximately 40 tire inspections (160 holograms). Figure 18 shows the film magazine removed for loading.
- A control console including solid-state electronics which controls all functions. Control is selectively automatic or manually actuated.

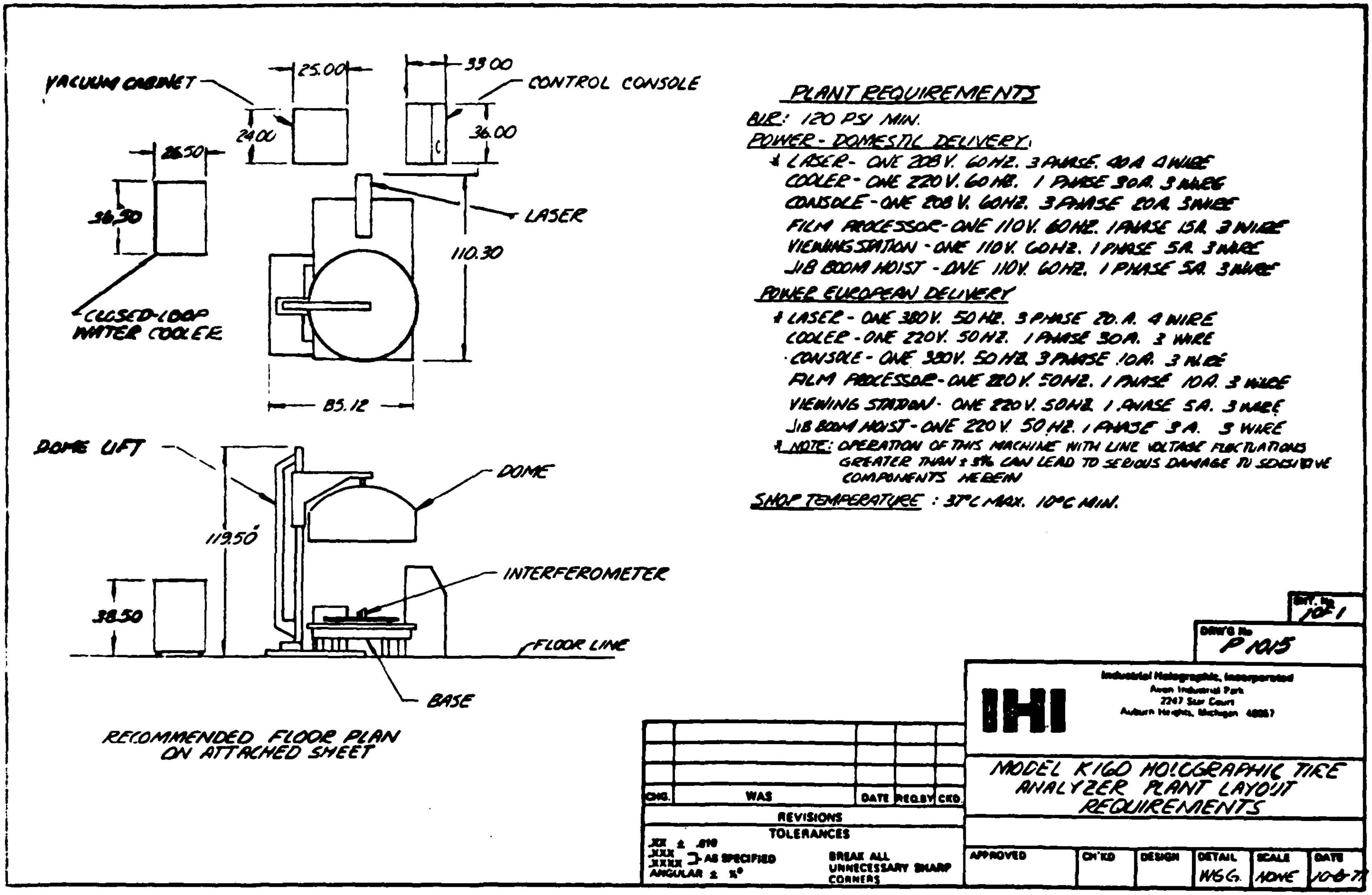


FIGURE 16. IHI MODEL K160 HOLOGRAPHIC TIRE ANALYZER

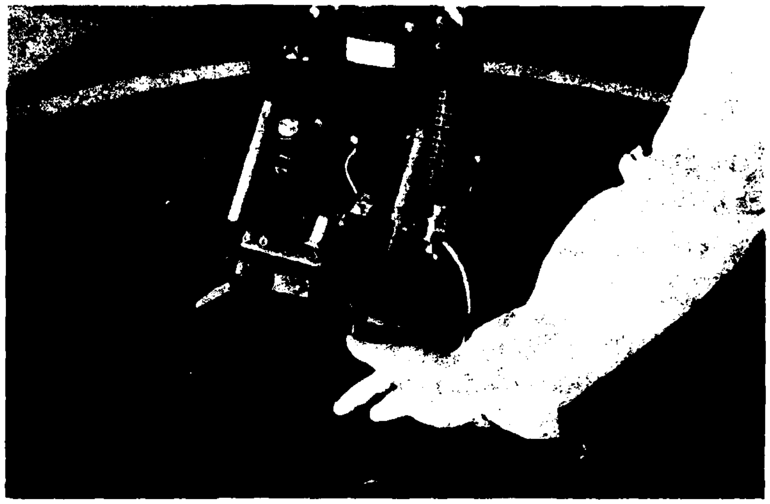


FIGURE 17. MODEL K160 INTERFEROMETER AT CENTER OF TURNTABLE.

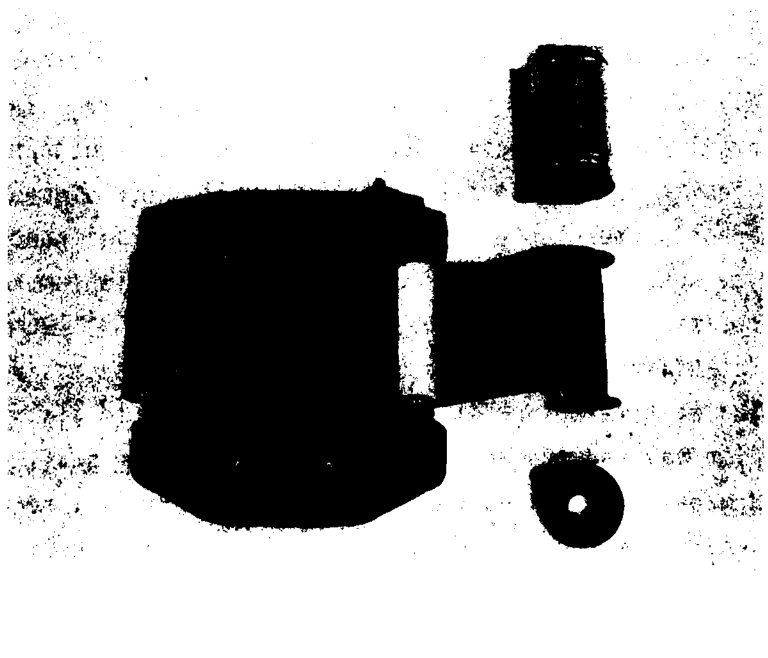


FIGURE 18. FILM MAGAZINE OPENED FOR LOADING.

- A jib boom crane for loading tires on and off the turntable.
- A tire spreader, which is a pneumatic actuated claw device used to spread the tire beads for insertion of spreader bars. Tire spreaders are optional equipment furnished with the inspection system. Commercial types are available at tire supply distributors.
- Spreader bar sets in different sizes.
- Turntable block sets. The turntable pan must be block supported at the appropriate height for the tire size to be inspected.
- Hologram viewing station. This is a table top viewer resembling a slide viewer. It is illuminated by a laser light source.
- In addition to the equipment, sufficient flat horizontal space (floor) must be provided to permit flat storage of 15 to 20 tires for dimensional stabilization after spreading.
- A dark room facility for developing the film holograms must be provided.

Figure 19 is a photograph of the BFGoodrich Akron hologram facility. The dome is in the closed inspection position. The control console is to the right of the base, the jib boom crane on the left and the other consoles partially concealed to the right of the dome. Figure 20 is a closeup of the consoles. The tires on the floor have been spread and are stabilizing. Chalk marks on the tire sidewalls are quadrant markings applied with guidance from a template to guide placement of the tire on the turntable and to provide rotational reference in locating defects.

Usually four holograms are produced for each tire. These are identified as quatrants 1 through 4, dividing the tire into 90° quadrants in a clockwise direction looking at the serial number sidewall, which faces upward with the tire on the inspection turntable, and considering the serial number to represent 0°. There may be some overlapping of quadrants at the hologram edges and there is some lack of precision in locating the 0° position.

The stabilization of tires after spreading is necessary because the tire creeps for a period of time before it completely readjusts to its new spread position. Stabilization may require 30 minutes depending on the stiffness of the tire and the spread magnitude. Tires should be handled carefully before and after spreading and when loading on the inspection turntable to avoid "bruising". For example, if a tire is dropped on a corner of the tread causing local deformation, that deformation does not immediately fully recover. Most of the deformation immediately recovers but the remainder recovers over a relatively long period of time, perhaps one hour.

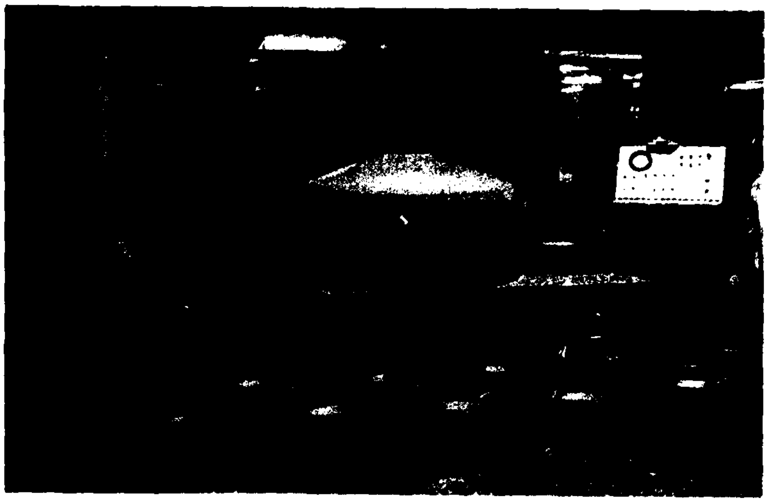


FIGURE 19. K160 HOLOGRAPHIC TIRE ANALYZER WITH SPREAD TIRES STABILIZING ON FLOOR.

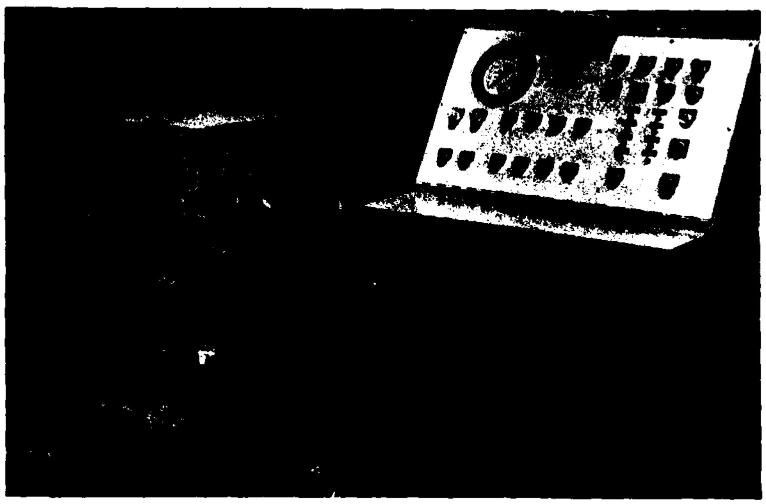


FIGURE 20. CONTROL CONSOLE AND SUPPLY CABINETS FOR K160 ANALYZER.

Since there is approximately 20 to 30 seconds between hologram double exposures(the time required to evacuate the dome volume) any surface creep caused by bruise recovery or insufficient spread stabilization could resemble a defect on the hologram.

When the tire is loaded on the inspection turntable, the dome is lowered onto the base and uncoupled from its lift. The photographic process is then initiated at the control console. It can be selectively manual or automatic. The tire is illuminated by the laser and photographed. Without moving tire or film, a vacuum is induced in the inspection chamber and the tire is again photographed, double exposing the hologram. The turntable then rotates 90° to place the second quadrant of the tire surface in the camera field of view; while the camera advances the film to the next frame position. The vacuum is released so the tire is again in an ambient pressure environment. The second quadrant is then double exposure photographed. The process is repeated until all four quadrants have been photographed. The dome is then raised and the tire is off-loaded and a new tire loaded for inspection.

The NRC/GCO Model AT-12 Holographic Tire Analyzer used by NRC in their tire inspections is shown in Figure 21. This system is an earlier model by a different manufacturer than the K160 model by IHI,but it includes essentially the same system elements with differences in detail.

In using their equipment,NRC made holograms of each tire in both the serial-side-up and serial-side-down positions and compared corresponding holograms for each quadrant to eliminate "spurious fringes". This may indicate that this system is not as effectively vibration isolated as the K160 system and that "spurious fringes" could be caused by vibration from external sources.

3.4.4 COST OF HOLOGRAPHIC SYSTEM

The cost of a holographic inspection system could vary with the equipment options selected and estimated prices by IHI and NRC, which are slightly different. We consider the IHI Model K160-2 to be a suitable basic equipment package for a tire retreader and the price for equipment only is estimated at $125,000.

Installation cost is estimated to be $15,000.

Maintenance cost is estimated at $10,000 annually including a manufacturers service policy.

No unusual utility services, safety precautions, or environmental precautions are needed.

Operators of the test equipment should have a high school education and should exhibit some mechanical skills. Their training would require one month

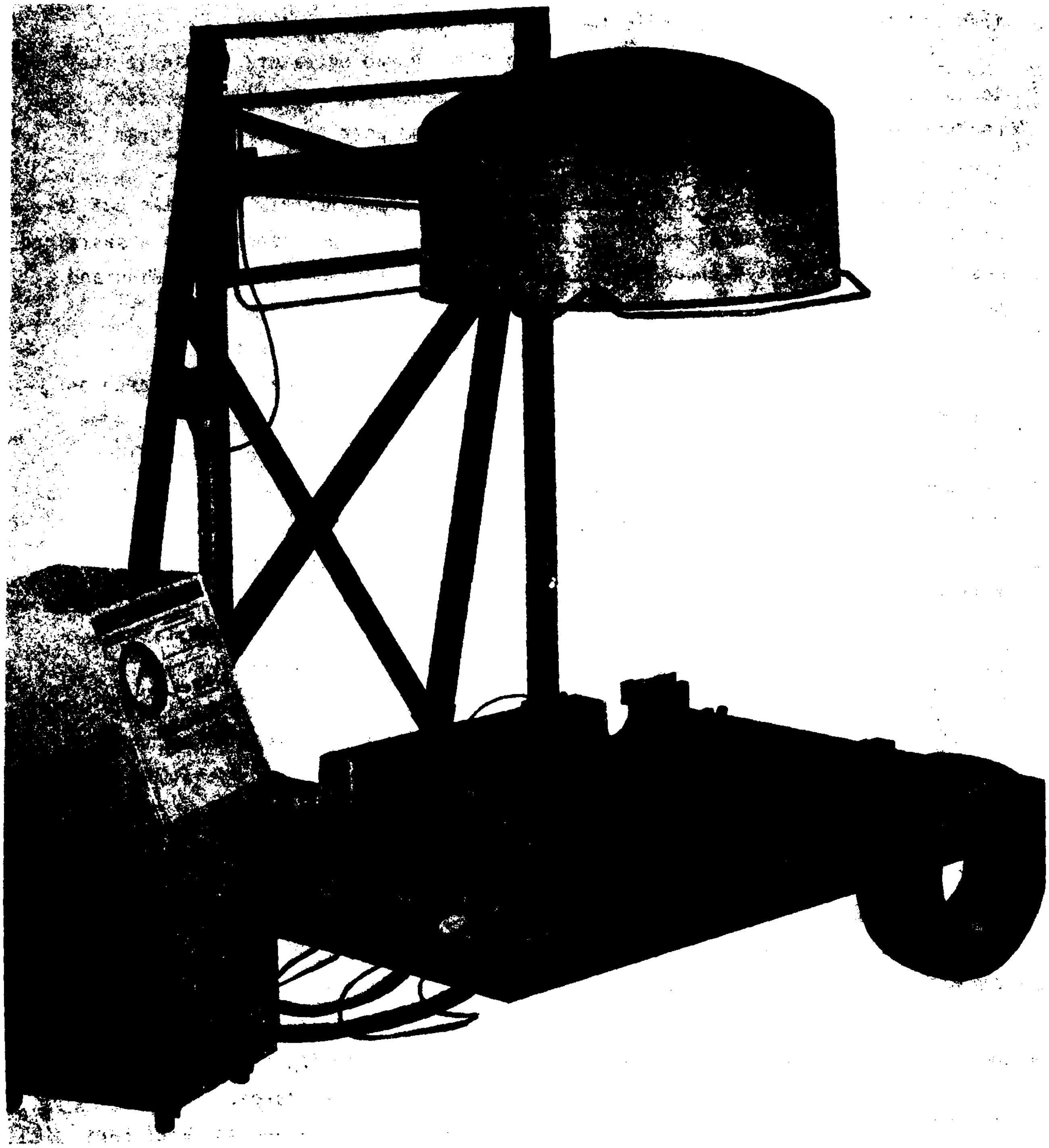


FIGURE 21. NRC/GCO HOLOGRAPHIC TIRE ANALYZER.

including a one week course at the equipment supplier's facility where they would be taught routine set-up, operation, maintenance and analysis. The cost of this factory training program is included in the purchase price.

It is expected that one system would require two operators to handle the tires and to accomplish the machine inspection function. A third operator-analyst would be needed to accomplish the dark room work and to do hologram viewing, analysis, and recording.

Total machine time for a tire inspection is approximately 3 minutes but is estimated that 60 to 80 tires per an 8 hour shift could be inspected on a sustained basis allowing for size-change set-ups, routine maintenance, tire spreading and handling, etc.

Film materials and supplies are estimated to be $0.75 per tire.

The equipment manufacturers can provide basic defect analysis guidance on aircraft tires. When tires of new sizes and construction are encountered, some developmental inspection and cut-up of tires may have to be done to establish optimum test and analysis procedure.

3.4.5 INSPECTION PROCEDURE AND ANALYSIS

The inspection procedure has been partially explained in describing the test equipment and its function in report section 3.4.3.

The normal inspection and analysis procedure on the two different types of equipment used are essentially the same. Both types of equipment normally provide only crown, shoulders, and upper sidewalls inspection of an aircraft tire because of the limited spread of the beads which can be accomplished in these stiff tires without causing permanent bead distortion. Only this "normal" inspection was done on the IHI equipment at BFGoodrich. NRC used a modified inspection technqiue in an effort to inspect more tire surface area.

The BFGoodrich procedure is representative of that currently in use to qualify tires for retreading, and is described first. The additional procedure employed by NRC is then described.

3.4.5.1 HOLOGRAPHIC TIRE INSPECTION AND ANALYSIS - BFGOODRICH

Prior to holographic inspection, tires have been inspected and accepted by the direct visual surface inspection and by air needle injection. The tires are sorted by size to minimize inspection equipment set-up changes.

The tires are spread on a tire spreader and 3 to 6 flanged spreader bars are inserted to hold the beads in spread position. The number of spreader bars depends on the bead diameter. The spreader consists of a pair of air actuated "claws" that grip opposite bead toes and pull them apart a selected distance.

A spreader bar is inserted adjacent to the claw. The spreader bar is a metal rod with an angle flange on each end so that one leg of each angle rests against a bead toe supporting the spread bead laterally, and the other leg of each angle rests against the bead flat to keep the spreader in place. The tire is rotated in the spreader for a succession of spreads and bar insertions until the entire bead circumference is spread and supported by bars. See Figure 22.

Handle the spread tire carefully to avoid "bruising". Lay the tire flat on the floor or other smooth surface with the serial number sidewall(SS) up. Using a template guide, quadrant markings are chalked on the sidewall as a guide for locating the tire on the inspection turntable(Figure 22). If it is necessary to augment the reflectivity of the inside tire surface, the inside is sprayed with a white talc powder solution. The IHI system normally does not require dusting. The tire is allowed to stabilize in this position for a minimum of 20 minutes before careful loading onto the inspection turntable. Experience may indicate different stabilization times for different tire sizes and constructions.

The inspection machine operator observes the size of the tire to be inspected. He then adjusts the turntable pan height by supporting it on appropriate shim blocks so the camera aperture is at mid-height of the spread tire section. He selects appropriate camera aperture and exposure time, and vacuum level(usually 2 to 4 inches of mercury) by control console settings. The tire is loaded onto the turntable (using the jib boom lift) taking care to orient it so the first tire quadrant is in the camera field of view. He enters the tire serial number, camera and machine settings, and possibly a register number on a film log chart to identify the film frames with the tire. Sometimes the film register number is chalked onto the tire.

The dome is lowered onto the base and uncoupled from its lift.

The photographic sequence is initiated at the control console by pushing a button. Automatic sequencing is normally used, which controls the dome pressure, turntable advance, and film advance to produce the four double exposed holograms. Manual sequence is useful in determining optimum inspection conditions for newly encountered tire sizes or for special cases.

At the conclusion of the machine sequence the dome is connected to its lift and raised and the tire is off-loaded from the machine and another stabilized tire is positioned for inspection.

Actual machine time is approximately 3 minutes after size adjustments are made.

FIGURE 22. SPREAD TIRE WITH QUADRANT MARKINGS.

The inspected tire is returned to the spreader where the spreader bars are removed. The tire is then moved to a holding area awaiting disposition after the holograms are developed, viewed, and analyzed.

When the film roll in the camera is completely exposed it is removed and a new film roll is loaded, Figure 18. The film roll holds approximately 15 feet of 70 mm film, enough to inspect approximately 40 tires.

The exposed film together with the film log chart is sent to a dark room for developing. After developing the film strip is cut into 4-frame lengths, the holograms for the four quadrants of one tire, identified from the log and sent to the viewing area.

The viewer functions like a slide viewer. The film strip is manually fed through guides which position it under a magnifying lens where it is illuminated by a laser light source. An inspection chart is prepared by the inspector, on which he notes the location and identity of any defects detected in this inspection. The chart format used by BFGoodrich is shown in Figure 23. It is based on a format suggested by IHI. Different formats are in use by other users of holographic equipment. Generally, the forms provide for defect location by tire profile quadrant and section, as well as identification with the tire and hologram register number. The inspection chart and the hologram become a part of the inspection file record. Based on the results of this inspection, tire disposition will be decided and the inspected tires are appropriately dispatched from the holding area.

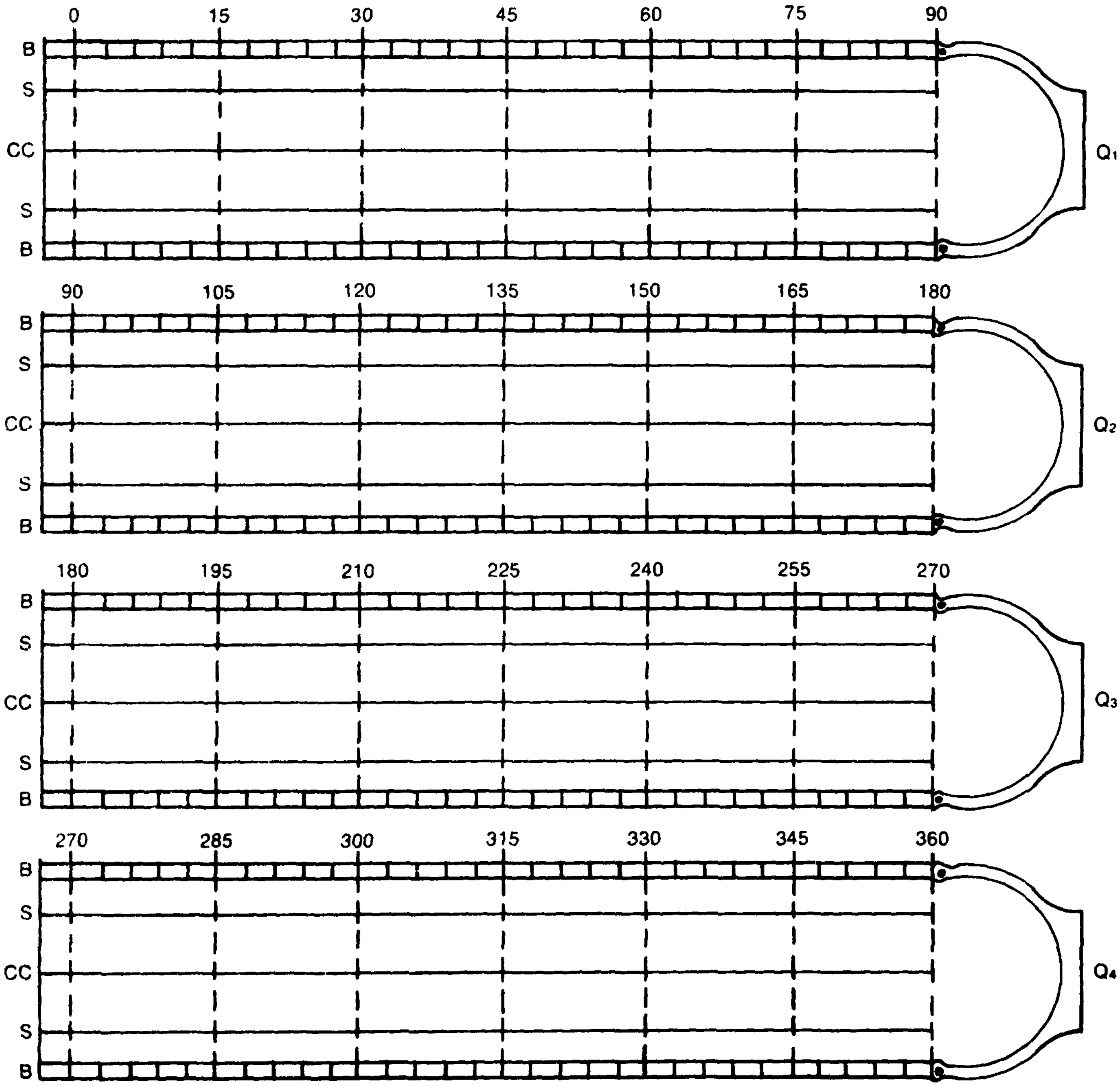
The inspection records, in addition to making an accept/reject decision on the tire, are useful to tire design engineers as guidance in upgrading tire design and in correcting special tire service problems associated with a particular air carrier or route. Tire defects can be identified on the hologram by the fringe line characteristics by a qualified inspector. The size of detected defects can be deduced by comparing the extent of the fringe aberration with holograms of similar size tires with standard size surface markings. Usually the inside surface of a tire exhibits molded-in ridge lines which are the impressions of air escape grooves in the tire cure bag. The spacing and arrangement of these grooves is characteristic of the tire size and manufacturer and is useful as a size comparator scale. These liner ridges are visible in the holograms.

Several photographs of holograms of tires from this evaluation study are presented here as examples. These include views from the new tires and the used tires, all holographed at the same vacuum level. These photographs were taken by a shrouded 35 mm camera focused on the viewer eyepiece using conventional black

B F GOODRICH HOLOGRAPHIC ANALYSIS

DOT NO. UP

REQUESTED BY	MILEAGE	SIZE	TEST NO.	SERIAL NUMBER
	DATE RECEIVED	DATE RUN	LOG NO.	TIRE OK
				REJECT



B = bead S = shoulder CC = crown center

COMMENTS

FIGURE 23. HOLOGRAPHIC ANALYSIS CHART.

TESTED BY

DEPT. 6140

BFG-12628

PRINTED IN U.S.A.

and white film. The hologram visible to the camera is more limited in extent than the view presented to the eye because the camera lens is fixed whereas the eye can be moved with respect to the viewer magnifying lens. The three-dimensional effect visible to the eye is lost to the camera and the image quality is somewhat diminished. The darkened areas at the sides of the photographs are also not seen by direct viewing.

Figure 24 is the junction between the fourth and first quadrants of test tire No. N88-7900. The bead flat is visible across the bottom of the picture. A flanged separator bar is at the right casting a shadow on the tire surface. Just to the left of that shadow is a small circle of fringes produced by a 1/2 inch diameter ply separation between the No. 1 and No. 2 plies, approximately 2 inches to the serial side(SS) of crown center(CC). Below it is a larger liner blister separation of 1-1/2 inch diameter on CC. Both of these separations are close to the surface and their included circular fringe lines are so close together they have blurred out in the photograph. These are both located near 0^{o} rotation.

Figure 25 is the third quadrant of the same new tire. To the left at CC is a 1 inch diameter ply separation between the No. 13 and No. 14 plies. To the right and higher in the photograph is a 1/2 to 3/4 inch separation between the No. 13 and No. 14 plies. Just above the right spreader bar flange is a half-round fringe which may be part of the fringe of a 1/2 inch upper sidewall or shoulder separation. The scattered band of small circle finges 2 inches above the bead from the right spreader, diminishing toward the left, is a band of small separations caused by liner porosity - probably caused by poor cure bag contact during vulcanization. The diagonal cure bag impressed ridges on the liner are clearly visible on these holograms of new tires.

Figure 26 is the second quadrant hologram for test tire No. N88-7901. At left lower middle is the fringe of a 1/4 inch diameter separation between the No. 9 and No. 10 plies in the opposite serial side(OSS) shoulder at 130^{o} rotation.

Figure 27 is the fourth quadrant of the same tire showing a 1-1/4 inch diameter shoulder separation between the No. 9 and No. 10 plies. A diagonal band across the center is a wide liner splice with a very small blister in the splice 2 inches from the top of the photograph.

Figure 28 is the second quadrant of tire No. N66-0773,#2, an R7(seven retreads) tire by a different manufacturer. Notice the closeness of the fringe lines as compared to the previous new tire holograms. The oval outline to the left is a balance pad which has some tiny separations between pad and tire liner. No separations are visible in the tire but notice the upper left to lower right line of fringe aberrationswhich indicates a loose ply splice at an unknown ply position.

FIGURE 24. HOLOGRAM, FOURTH QUADRANT, TIRE NO. N88-7900.

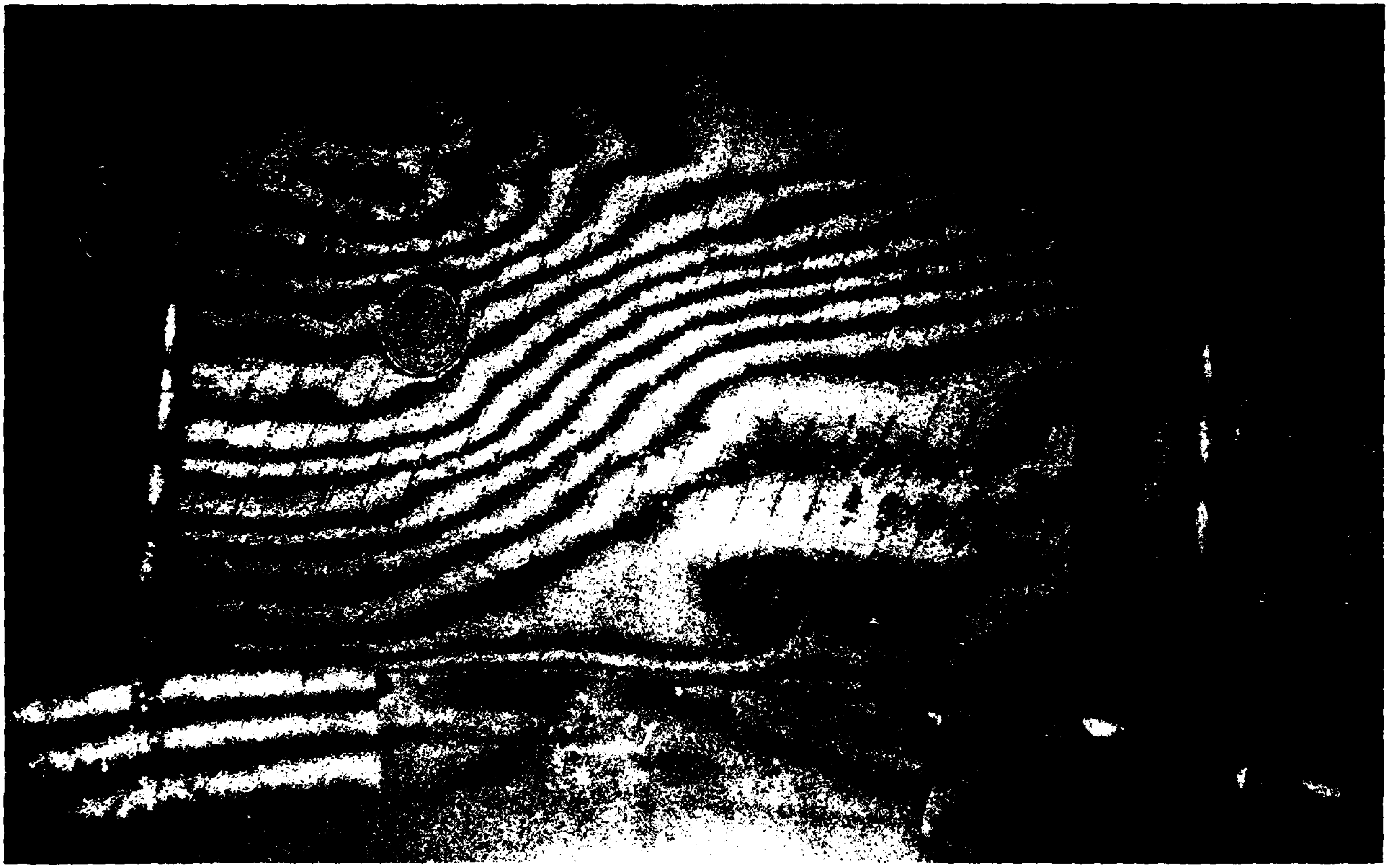


FIGURE 25. HOLOGRAM, THIRD QUADRANT, TIRE NO. N88-7900.

FIGURE 26. HOLOGRAM, SECOND QUADRANT, TIRE NO. N88-7901.

FIGURE 27. HOLOGRAM, FOURTH QUADRANT, TIRE NO. N88-7901.

FIGURE 28. HOLOGRAM, SECOND QUADRANT, TIRE NO. N66-0773,#2.

FIGURE 29. HOLOGRAM, FOURTH QUADRANT, TIRE NO. N66-0773, #4.

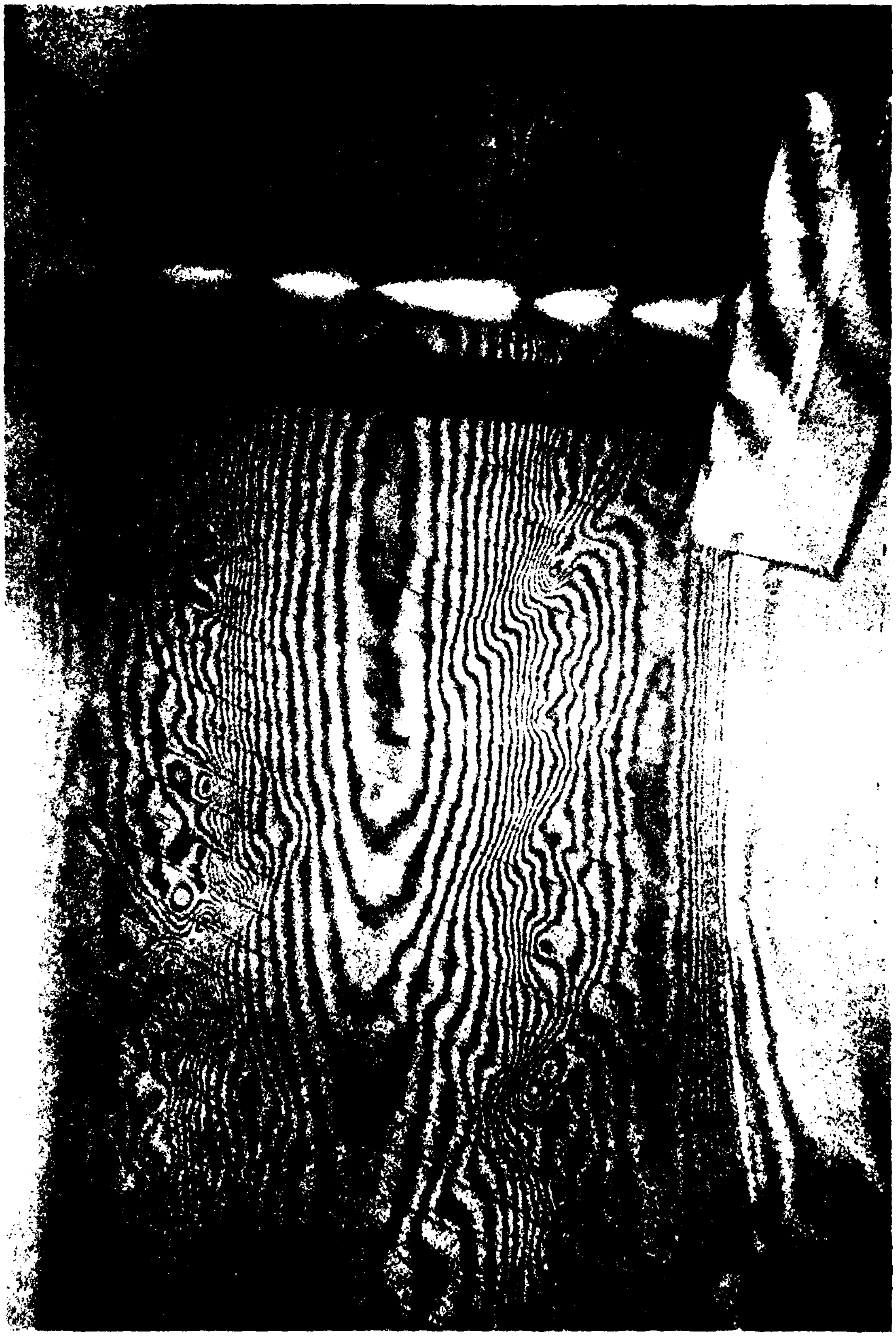


FIGURE 30. HOLOGRAM, FOURTH QUADRANT, TIRE NO. N66-0773,#6.

Figure 29 is the fourth quadrant of tire No. N66-0773,#4,an R5 tire. Again notice the close fringe lines in a used tire and the diagonal fringe aberrations of two loose splices which actually cross(although perhaps not in consecutive ply layers). Separations sometimes develop atthese cross-over points or where the loose splice crosses the shoulders.

Figure 30 is the fourth quadrant of tire No. N66-0773,#6,an R6 tire showing extreme fringe closeness. Again loose splices are evident with small separations starting where the loose splices cross the shoulders. A large double lobed separation is evident to the lower right of the spreader bar in the OSS shoulder at 0^o rotation. This separation appears to be formed from two 1 inch diameter separations which have joined. These separations are between outer No. 12 to NO. 14 plies.

3.4.5.2 HOLOGRAPHIC INSPECTION AND ANALYSIS - NRC

The NRC inspection and analysis technique was essentially the same as that of BFGoodrich except that on these tires NRC performed extra inspections in an attempt to cover more tire surface and to eliminate spurious fringes to improve their confidence in evaluating the possible propagation effect on separations by the air needle injection method. These extra inspections are not representative of "normal" qualification for retread inspection. The procedural differences are briefly outlined below.

In order to detect the tire degradation due solely to the standard air needling test, NRC chose to examine two separate and distinct parameters:

- Size of separations in the casing body plies within the shoulder-to-shoulder region.
- Visual estimate of casing response to uniform stress by examining the relative complexity of background fringes.

While the first parameter could be easily examined by standard holographic testing procedures, the second required an additional tire handling step. To remove as much experimental error as possible, the tire was first holographed in its normal S/N UP position. Then it is reholographed in the S/N DOWN position. Only those fringer-patterns common to both examination positions were trusted to represent the tire's response to stress. Any differences simply represent different stress conditions solely due to the tire's unique position in the Analyzer.

The rule for visually judging the quality of background fringes involved both the "before-to-after air needling" (B-A) comparison index together with the "reversal" comparison index. Specifically, if the reversal index was higher than the B-A index, the resultant change in background fringes was considered to indicate

zero tire degradation. If the B-A index was higher, the resultant air needle-induced change was considered to be the difference between the two indices.

NRC used a different inspection report chart format(Figure 31) which accomplishes the same purpose of mapping the location of defects as does the Figure 23 chart. In addition to marking the location and describing detected defects, the outline of significant fringe pattern areas was marked and shaded on the charts, for comparison of the "Before" and "After" air needling holographic inspections.

This comparison analysis for degradation was a unique and time consuming process.

Some holograms were also made with the tires in tilted positions in an attempt to inspect the lower sidewalls. The resulting holograms were of dubious quality and were not included in the defect analysis.

3.4.6 NEW DEVELOPMENTS IN HOLOGRAPHY

A number of size variations of the IHI Model K160 Holographic Tire Analyzer are available along with optional accessories from IHI. A partial list follows:

- A double 48" dome Tire Analyzer with common base inspects two tires simultaneously.
- Larger sizes of single dome types(94 inch, 120 inch, 130 inch, 140 inch dome diameters).
- More control automation for beam ratio adjustment, diagnostic messages, recording of film usage and number of tests, printing of identification numbers on film.
- Automatic film processor.
- Dual interferometers for recording two different view holograms simultaneously.
- Television holograph viewer.

IHI is developing automatic computer scan techniques for automatic computer analysis of a televised hologram image.

IHI is also working on an inspection technique which they call "Shearography" which uses a different optics system on the basic holographic tire inspection equipment. The tires are stressed at a higher vacuum than for holographing and the resulting photographic image eliminates background fringe, indicating only anomalies.

TIRE INSPECTION REPORT

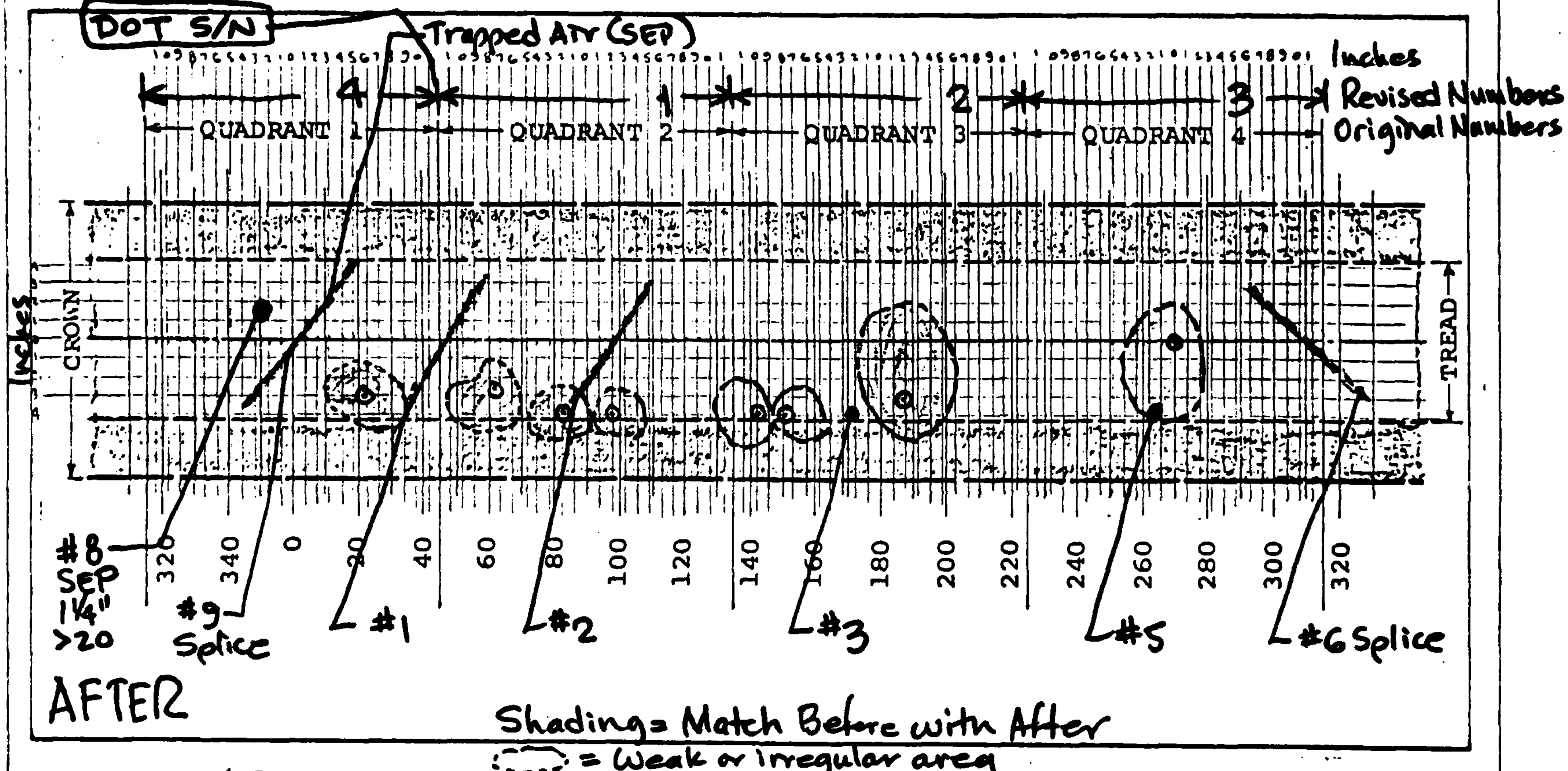
Date: Aug. & Oct. 1978 Time: ______

Operator: J. Thomasson & D. Terry

Customer: Goodrich (FAA)

Contract: ISD 1029

Inspector: J. Thomasson



Tire Type: AIRCRAFT 34-11/22

Tire I.D.: N88-1901

Vacuum :

NRC I.D. : TBX2482 #4-2 (S/N UP) #26-2 #4-2 (S/N DN) #27-2

Anomaly 1
- Classification: SPLICE
- Size :
- No. of Fringes:
- Est. Depth :
- Comments:

Anomaly 2
- Classification: SPLICE
- Size :
- No. of Fringes:
- Est. Depth :
- Comments:

Anomaly 3
- Classification: SEP
- Size : 1/4" dia
- No. of Fringes: 2
- Est. Depth :
- Comments:

Anomaly 4
- Classification:
- Size :
- No. of Fringes:
- Est. Depth :
- Comments:

Anomaly 5
- Classification: SEP
- Size : 1/2" dia
- No. of Fringes: 10
- Est. Depth :
- Comments:

FIGURE 31. NRC HOLOGRAPHIC ANALYSIS CHART

NRC has a proposed equipment design(not yet produced) which they claim has some advantageous features. It is identified as "NRC TIRE INSPECTOR 4". The salient design features include:

- A miniaturized 35 mm holographic camera; which, together with the interferometer and a reflected illuminating source from the laser, rotates at the center of a stationary tire to photograph the entire tire perimeter. Its advantage is a faster scan and less vibration than in rotating the tire.
- A pivoting vacuum chamber dome that raises only far enough to clear the tire then rotates with the lift boom to provide a clear overhead for tire loading.

A West German manufacturer, Rottenkolber Holo-System GmbH, is offering a holographic tire inspection system with some unique features which may be advantageous for use in a retread production facility.

This system, by use of a vertical interferometer camera located appropriately below tire level, and a spherical mirror located at the tire center axis, photographs the entire tire circumference on a single film frame. See Figure 32.

The camera uses a 35 mm film of a photo-thermosensitive type. After the necessary double exposure, the film is developed on the camera back plate in its exposure position by a hot air jet in approximately one second.

A video camera mounted behind the film can immediately scan the developed film and transmit its image to a video screen on the control console for inspection by the console operator. The camera views approximately 1/6 of the tire circumference at one time and can be moved by console operator control. A digital position indicator on the console provides a readout of the profile angle orientation in view on the video screen.

The need for only a single hologram for the complete tire circumference and the fast film developing and viewing permits a quick decision on the acceptability of the tire for retreading or return to service while the tire is in the inspection machine. There should be no need for holding tires for that decision until a complete film cassette is exposed, developed, and viewed as with the wet-processing silver halide film holograms.

By raising or lowering the tire with respect to the spherical mirror additional inspection views can be holographed, Figure 33A and Figure 33B. As shown in the Figure 32 tire/mirror arrangement, a crown-shoulders inspection of a tire can be done with a single hologram. If an outer sidewall inspection is desired the tire must be moved as shown in Figure 33B. To holograph the other outer sidewall the

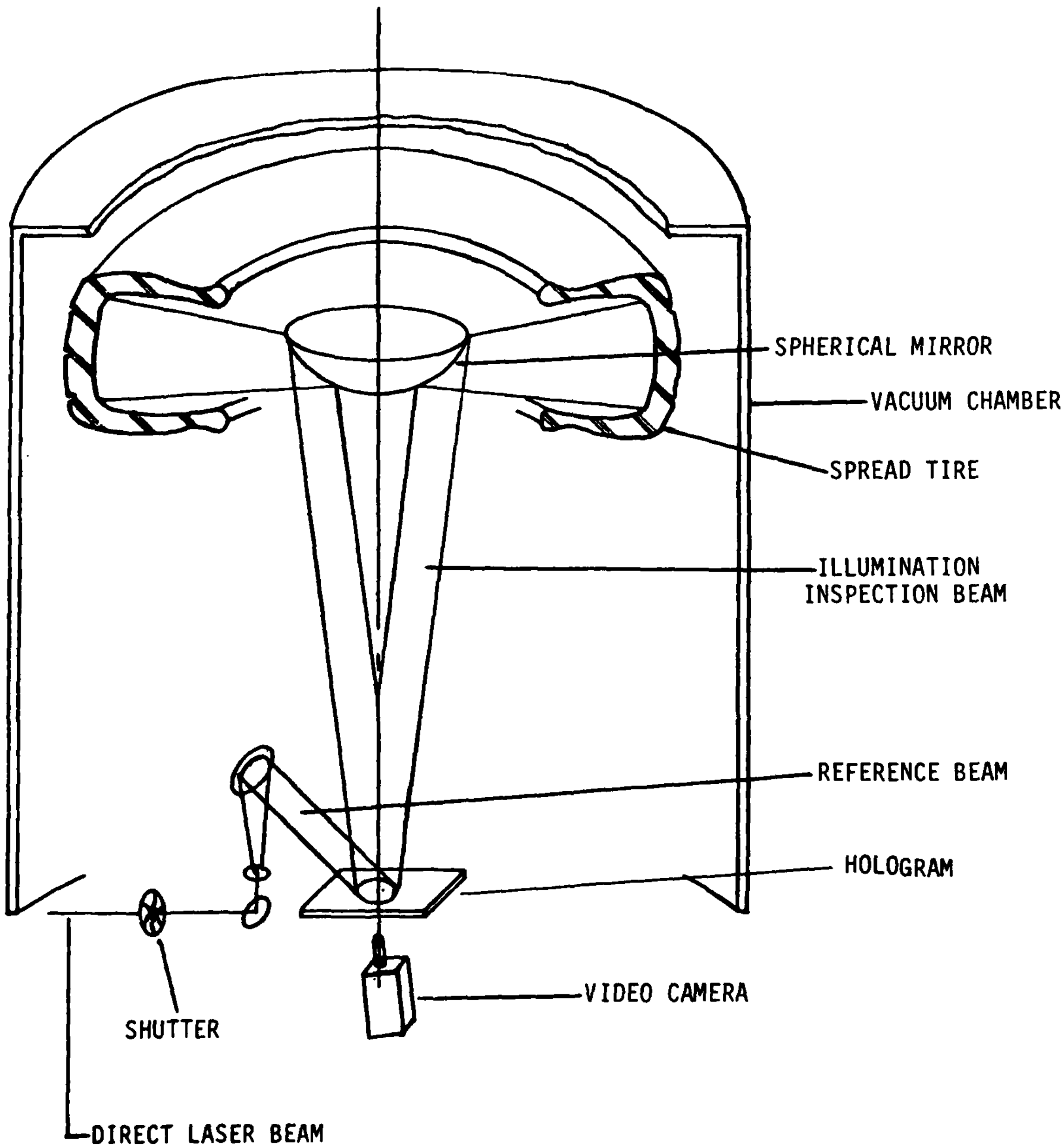
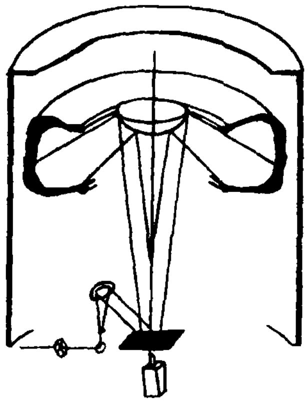
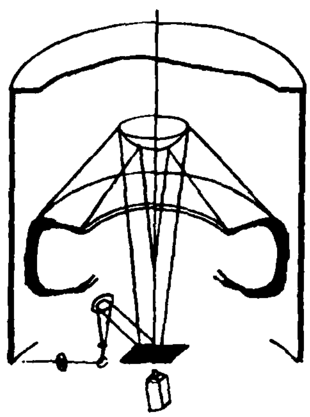


FIGURE 32. ROTTENKOLBER HOLOGRAPHIC INTERFEROMETRY USING SPHERICAL MIRROR AND VIDEO SCAN.



This method may be used to inspect sidewall and bead, dependent on tire spread and diameter. The tire elevation must be lower with respect to the mirror, as compared to the elevation for a crown and shoulder inspection. The tire must be turned over and tested again for the other half-crown-bead.

FIGURE 33 A. HALF-CROWN-BEAD INSPECTION.



This method may be used to inspect the sidewall and bead when the tire can be spread very little. The tire elevation is lowered with respect to the mirror as shown. The tire must be turned over to inspect the other sidewall and a third inspection with the tire elevation raised would be needed for the crown-shoulders.

FIGURE 33 B. OU.SIDE SIDEWALL INSPECTION

tire would have to be turned over and holographed again. Where tire spread permits it is possible to do a half-crown-bead inspection as shown in Figure 33A, then turn the tire over to holograph the other half-crown-bead.

A single Rottenkolber Model HRT 56, capable of inspecting aircraft tires to 56 inches outside diameter, would serve as a basic inspection unit for a retreader.

Remote video viewing stations are available for remote viewing of holograms. A video tape recorder can be used for storage and audio recording capability is available for voice recording inspection comments.

The system cost is approximatley $25,000 more than an IHI 160 system.

3.5 ULTRASONIC INSPECTION METHOD

3.5.1 GENERAL

Several different systems for inspecting the integrity of the laminated structure of a tire have been developed which utilize detected variations in sound waves passing thorugh the tire structure to indicate structural anomalies in the tire.

These are of two general types:

- Thru-transmission types utilize a transmitting device which generates a sound wave near one surface of a tire carcass and one or more receiving devices located on the other side of the tire carcass which detect the sound wave after it passes through the tire and converts the intensity of the received sound into an electrical voltage signal which can be displayed as a wave form trace on an oscilloscope. When an anomaly, such as a ply separation, is in the path of the transmitted sound it changes the wave form in a manner characteristic of the anomaly. A separation markedly reduces the intensity of the received sound. By comparing the altered wave form produced by the sound received in a region of a tire which contains an anomaly with that of a corresponding non-anomalous region, the presence of an anomaly and, perhaps, the type and size of the anomaly can be recognized.
- Pulse-echo types utilize the same device(transducer) to transmit a sound wave;and, at very short time intervals later,to receive the reflected sound waves from the interfaces of the tire laminate layers encountered by the transmitted wave. The reflected sound waves, or echoes,from successive laminations are received at successively later times,as the distance traveled by the transmitted and reflected sound increases. Each layer in the tire laminate affects the reflected

wave form in accordance with that layer material's sound transmission and sound impedance characteristics, as does an anomaly within the laminate. On an oscilloscope display, the portion of the wave form associated with a laminate layer or an anomaly can be associated with that layer or anomaly by its time of appearance on the wave form which is associated with the distance from the transducer. Separations tend to act like air layers,producing relatively intense reflections and severely attenuating transmission so that reflections from succeeding layers are considerably diminished. Since the time intervals between reflections are very small, ultra high frequency sound is utilized for the transmitted wave to reduce overlap of the wave form.

The tire being inspected by a sonic method may be surrounded by various media through which the sound travels from transmitter to tire to receiver, since the transducers are normally not in direct contact with the tire surface. The media is usually air or water.

Attempts were made to obtain inspection sources representing several sonic system types(for the test tires in this program), but only one source was obtained because of non-availability of other test equipment or because the equipment did not inspect enough of the tire surface (a crown and both shoulders inspection being considered minimum).

3.5.2 SOURCES OF INSPECTION AND INFORMATION

The test system used for evaluation of ultrasonic inspection is located at the U.S. Dept. of Transportation, Transportation Systems Center, Cambridge, Massachusetts. This sytem is somewhat unique in the manner in which it processes the acoustical data. It is the result of early work done by R. P. Ryan of DOT (References 6 and 7)and eventual design and construction by Teknekron,Inc, Berkeley,California.

The eight test tires were inspected twice at this facility with some changes in the type and arrangement of the transducers for the second test in order to improve its effectiveness.

This testing was observed by Mr. S.J. Caprette of the BFGoodirch Research and Development Center, Brecksville,Ohio, who also provided the personal contact with DOT and Teknekron,Inc. to obtain system and inspection methodology information and who contributed most of the written description of this sytem.

Actual testing was done under the supervison of Mr. S.N. Bobo, who also did the analysis of the test data.

System information was obtained from Mr. Bobo and Mr. R. P. Ryan of DOT and from Mr. Morris Ho and Mr. Michael Hall of Teknekron,Inc., 2118 Milvia Street, Berkeley, California.

3.5.3 DESCRIPTION OF EQUIPMENT FOR ULTRASONIC SYSTEM

The ultrasonic inspection system used in this evaluation was designed primarily for auto and truck tires, not aircraft tires. The design was not intended for a production shop and includes more elaborate and versatile electronics than would be required of a production shop design.

The system requires that the tire be mounted on a split rim wheel and inflated with low pressure air sufficient to maintain a bead seal when the tire is immersed in water. The actual inspection is performed under water in a 4 foot deep tank - see Figure 34. There are three split-rim tire stations on the ends of the three arms of a large spider or vertical carousel. Whenever one arm is at the load/unload position, the other two stations are totally submerged, one ata debubbling position, the other at an inspection position. Once a tire has been mounted, it is moved to the debubbling station by a 120 degree rotation of the carousel for removal of air clinging to the surface by a set of high-velocity water jets. At the same time, the previously debubbled tire is carried to the inspection station, and the previously inspected tire is brought to the unload/load station.

Total immersion and debubbling rather than partial immersion is used to avoid any possiblity of difficulties which could be caused by the reflection of ultra-sound by air bubbles clinging to the surface of a partially immersed tire as it rotates for scanning.

In the inspection station, a set of transducers is arranged in a ring around the cross section of the tire. The transducers are pulsed in sequence as the tire rotates and the returning echo signals are processed in sequence with the aid of electronic switching. Thus, the entire surface of the tire is scanned during a single tire revolution. Each of the transducers is pulsed 1000 times during the 10 second scan, so that the tire is examined at 24,000 spots on its surface. This system provides 24 transducers(limited by the available electronics channels). The scan may use all or only a portion of the available transducers.

The flat circular faces of the cylindrical transducers must be located tangent to the layered tire interface and critically spaced from the tire inside surface. Each transducer scans a section width on the tire approximately one inch wide. The transducers must be repositioned for each different tire section profile. To facilitate such mechanical alinement, the transducer support yoke is pivoted on sleeve bearings at the main axis of the spider, so that it can be swung up near

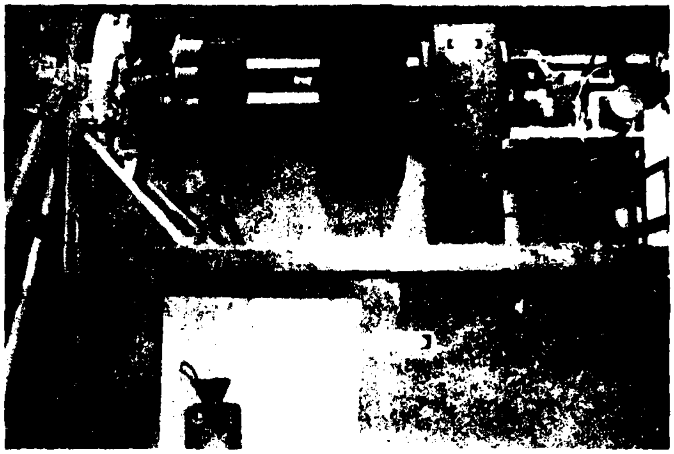


FIGURE 34. PULSE-ECHO ULTRASONIC TIRE INSPECTION EQUIPMENT TIRE CAROUSEL AND WATER TANK.

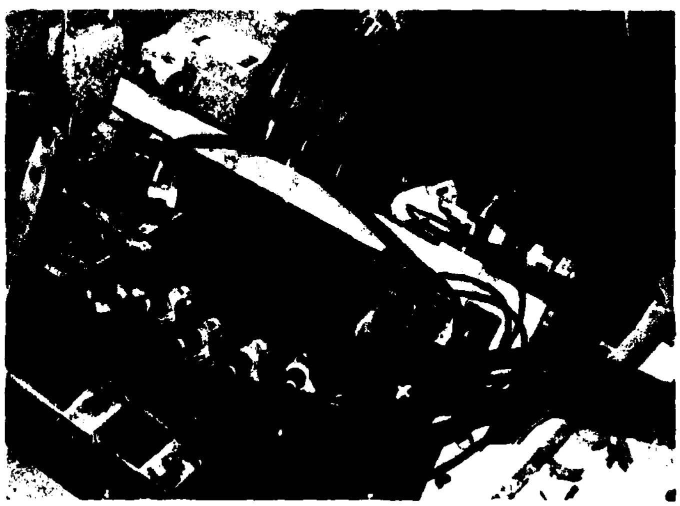


FIGURE 35. TRANSDUCER ARRAY RAISED ABOVE WATER SURFACE.

the surface of the water. The spider is stopped halfway in an index operation to bring the tire up to the surface, such that it will be in the same position relative to the transducers as in the inspection position. Thus, the transducer positioning adjustments involving manual adjustment of clamping screws, fixtures, etc., can be reached while the transducers are totally under water, and it is possible to observe the echo signals on an oscilloscope. The criterion for proper alinement is simple; i.e., the echo signals are maximized and the layered structure is resolved to the maximum extent possible. Referencing of the transducers relative to the outer surface of the tire is not practical because the outer surface of the tire is seldom parallel to the internal layered structure of the reinforcing materials. Figures 35 and 36 show the support yoke and transducers raised above the water to demonstrate their arrangement.

Figure 37 shows an overview of the scan-control and data-evaluation electronics. At the right side, there is a rack containing 24 pulser/receiver amplifiers, one for each of the transducers. The main rack, behind the operator's table, contains the control electronics and the signal-processing and display elements of the system. Lighted push buttons select and indicate scanning, signal-processing, and display modes. Scan-data displays are generated on a scan-converter image-memory tube and presented for evaluation on a large television monitor. Signal-processing is digitally controlled, and the scan-programmed signal processor provides up to 32 adjustable parameters which can have independent values for each of the 24 channels. A laboratory oscilloscope can be selectively triggered to monitor the effects of adjustments of the parameters for any one channel at a time.

To assist the operator in the managing and recording of these parameters, a minicomputer provides a tabular display of the parameter values and permits entry or alteration of selected parameters via the keyboard, and/or re-entry of parameter sets from a digital storage medium.

Either the scan-data image-format displays from the large television monitor, or the alphanumeric parameter displays shown on the small television monitor, can be printed on paper by a video-facsimile recorder.

A video tape recorder permits the raw, unprocessed echo signals to be recorded whenever a tire is scanned. Thereafter, any of the various kinds of signal-processing and display functions that the system is capable of can be accomplished from the tape-recorded signal, even after the tire is no longer available for tests.

During testing a wire is wrapped around the tire section as a selected 0° rotation reference line, usually at the DOT number or serial number of the tire as indicated in Figure 38. The transducers detect this wire and it permits

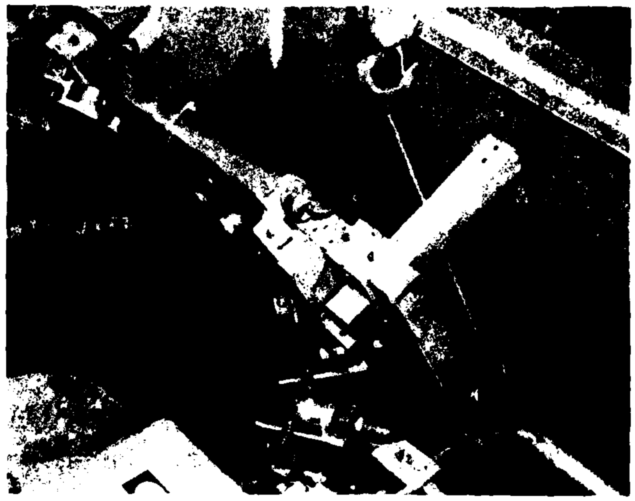


FIGURE 36. TRANSDUCER ARRAY YOKE RAISED ABOVE WATER SURFACE.

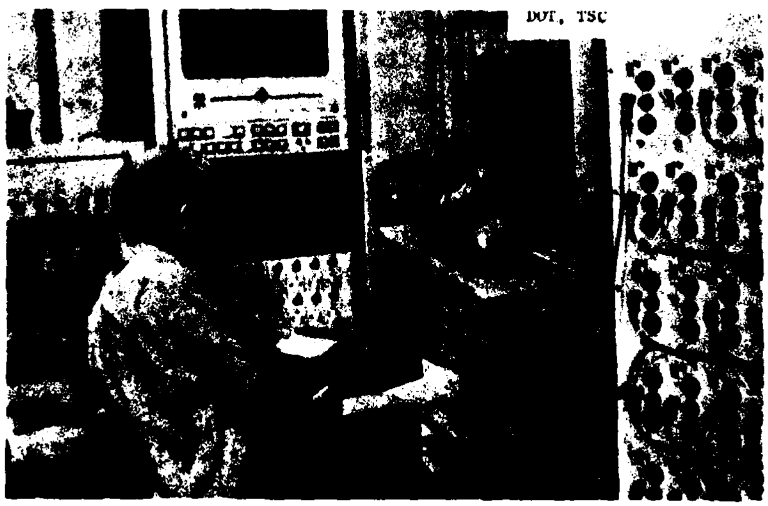


FIGURE 37. SCAN CONTROL AND DATA EVALUATION ELECTRONICS.

correct respective alinement of consecutive transducer scans when they are displayed side-by-side on the video screen.

The return echo signals from the transducers are processed and displayed on a video screen in a B scan format with the B scans of several transducers displayed side by side and oriented so that the $\theta = 0^{0}$ rotational position is at the top of the image for all scans or channels displayed and with scans in increasing $\emptyset$ angle order from left to right(Figure 39). Each B scan resembles an edge view of a cut around the tire circumference with the cut on the transducer axis. A schematic of a B scan format is shown in Figure 40. An idealized schematic of a single channel is shown in Figure 41. Note that the vertical lines observed in the display are only approximate representations of tire features. The acoustical echoes are phase sums of reflections from discontinuities in the acoustical path. For tires with few elements(plies) the correspondence is good but as the number of elements increase, as for 22PR aircraft tires, care in interpretation must be taken.

The results of this display format is a pseudo 3-dimensional picture of a tire. The ability to visually construct variations of display both in the θ and $\emptyset$ directions, as well as through the thickness of the tire simultaneously, provides a powerful tool for interpretation.

3.5.4 COST OF ULTRASONIC SYSTEM

Cost estimates for an aircraft tire inspection system derived from the design of the DOT system are based on information provided by Mr. Morris Ho of Teknekron, Inc., who designed and fabricated the DOT system. A brief Teknekron, Inc. report summarizing the features and costs of such a system is included in this report as Appendix A.

To summarize that report, the system cost for a 32 channel(transducer) system for aircraft tires with data display for manual analysis is estimated at $200,000 for the first system and $100,000 for succeeding systems.

Installation cost is estimated to be $15,000.

Maintenance costs are estimated to be $12,000 annually.

No unusual utility services, safety requirements, or environmental precautions are needed.

Operators who have a high school education and who exhibit some mechanical skills can be trained to operate the equipment in one month. Two operators would be required per shift for system operation.

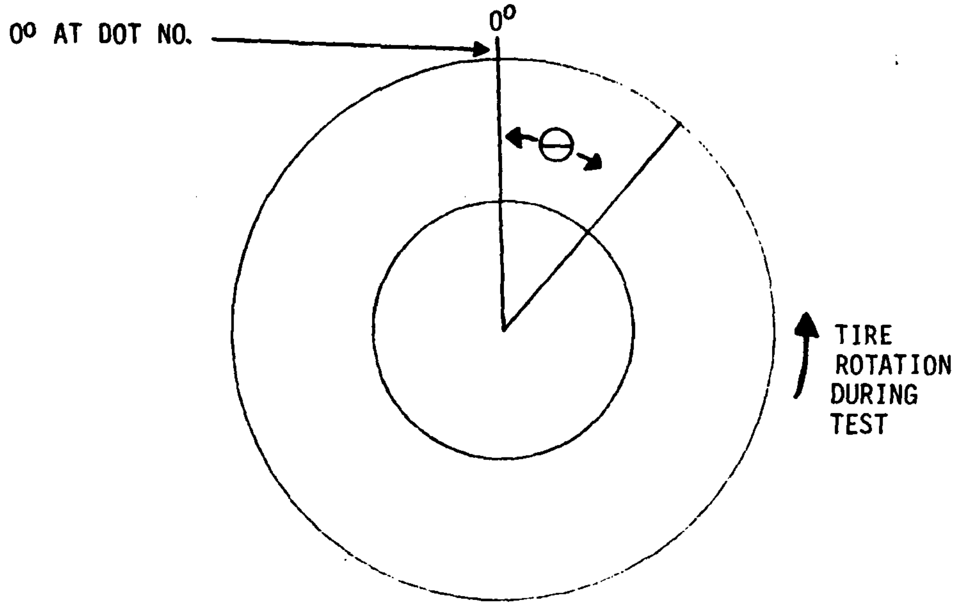


FIGURE 38. TIRE SCAN ROTATION ORIENTATION

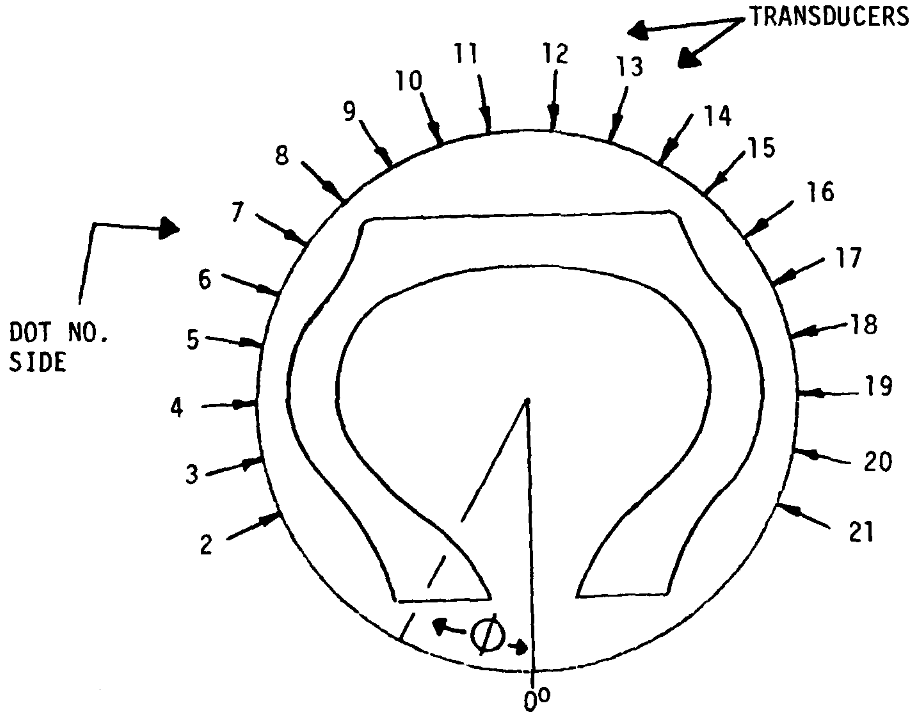


FIGURE 39. SCHEMATIC OF TRANSDUCER ORIENTATIONS FOR FIRST TEST SERIES.

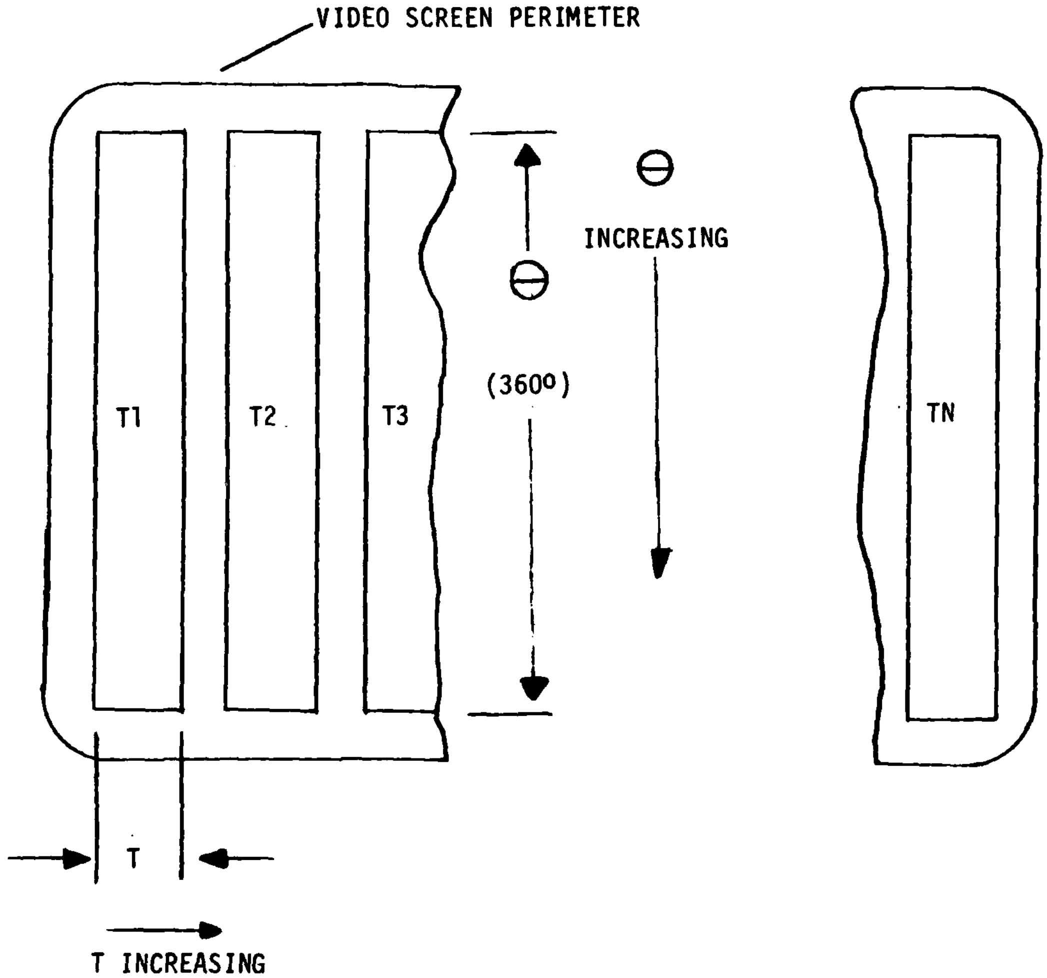


FIGURE 40. SCHEMATIC OF B SCAN DISPLAY FOR N TRANSDUCERS, T1, T2, T3, TN.

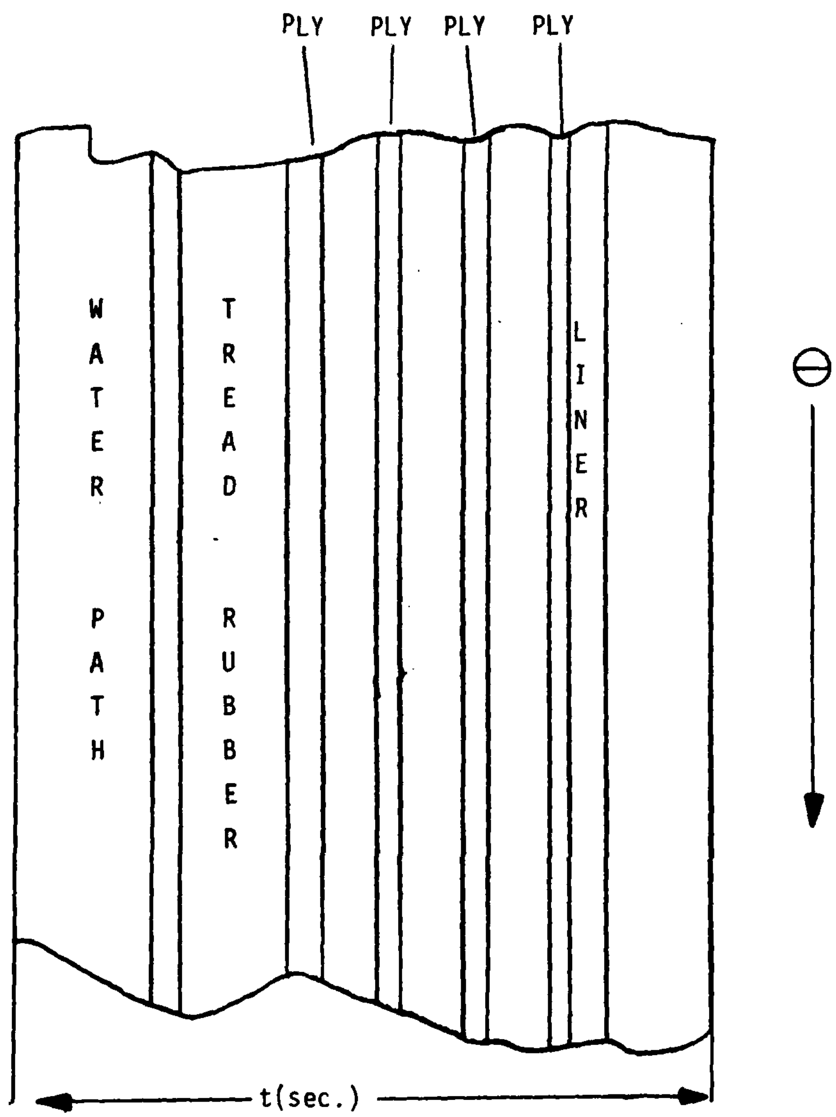


FIGURE 41. SCHEMATIC OF SINGLE CHANNEL B SCAN DISPLAY - NOTE DARK AND LIGHT LINE CORRESPOND ONLY APPROXIMATELY TO TIRE FEATURES

Total machine time for a tire inspection is estimated to be 2 minutes. Data analysis is estimated to require 5 minutes.

It is our opinion that the preceeding inspection time is optimistic over a sustained time period, and that 30 to 50 tires could be inspected in an 8 hour shift, depending on the number of tire size changes to be accommodated in that time period.

Since there is no extensive experience on this equipment in aircraft tire inspection, it is likely that a period of two or three months of development testing of tires of different sizes would be necessary to trouble-shoot and learn how to best use the system and to establish test and analysis procedures. This would include the need for cutting up tires to verify anomalies. This development testing should involve a tire engineer.

3.5.5 INSPECTION PROCEDURE AND ANALYSIS

Two series of inspections were made on the eight 34X11 aircraft tires. The inspection procedure is fairly simple after the equipment setup is accomplished; but, since aircraft tires of this size had not previously been inspected, a number of trial scans were needed to accomplish the setup and several compromises were necessary.

For the first inspection series these compromises were:

- Only 20 transducers were used as indicated in Figure 39; thus, the tire sections adjacent to the beads were not inspected.
- 2.25 MHz transducers were used. At this frequency,energy loss due to absorption prevented inspection beyond about 5-7 plies deep.
- The maximum time(t) for the B scan mode for a single channel was not great enough to display the entire acoustical path where adequate energy was available. For this reason the B scan displays for this first test series were begun beneath the outer surface of the tire as shown in Figure 42. Thus, neither the water-outer surface interface nor the air-liner interface was seen.

Figures 43 and 44 are photographs of two video displays each showing the B scans of 10 transducers displayed side by side with 0^{o}(serial number) orientation at or near the top edge of the display as indicated by the broken white line across the top of each scan. The solid black horizontal lines across some of the B scan displays are caused by loss of signal at some points and are not caused by structural features. The black checks, arrows, and circles are markings placed on the video-facsimile recorder prints during analysis and represent the locations of probable anomalies detected by the scans. The quality of the original video

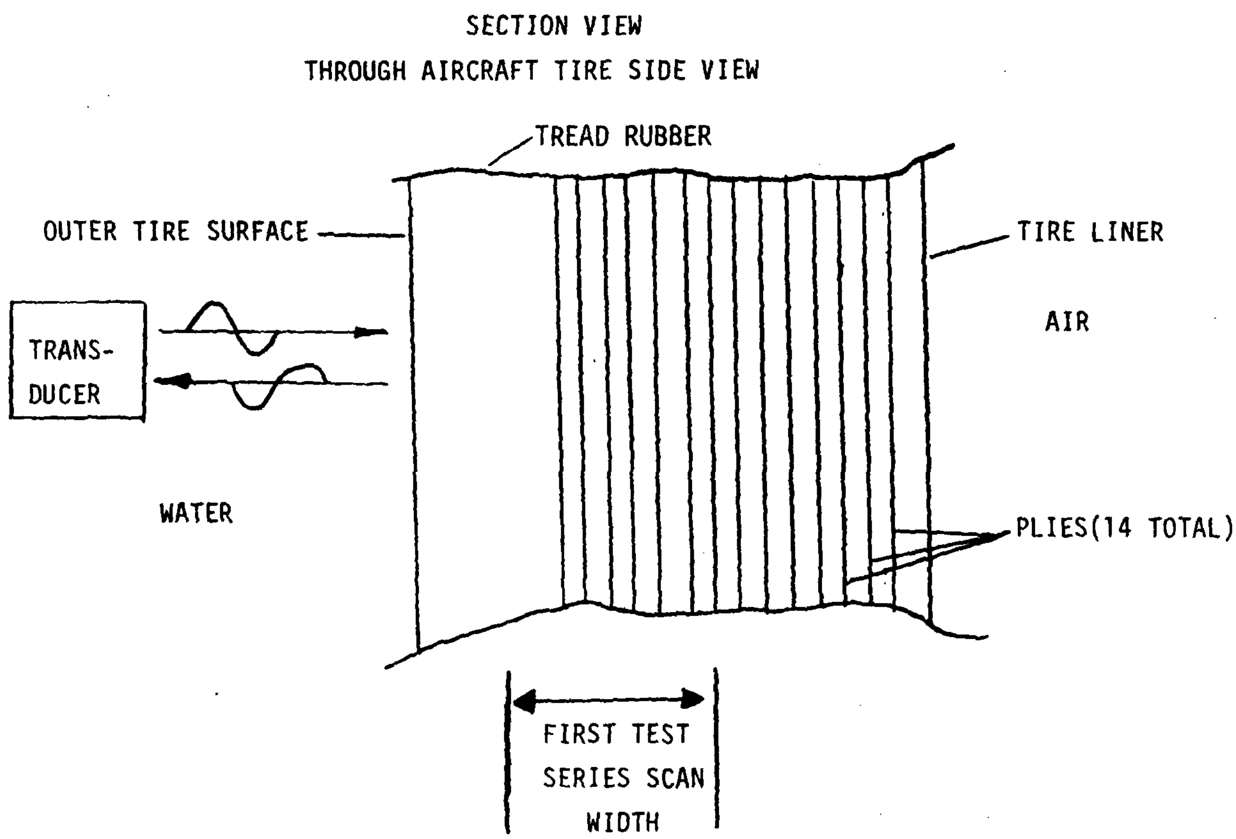


FIGURE 42. REPRESENTATION OF TYPICAL B SCAN TIME WIDTH FOR FIRST TEST SERIES

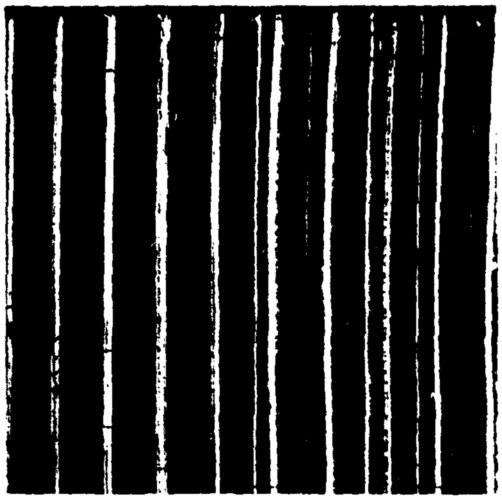


FIGURE 43. FIRST TEST SERIES B SCANS OF TIRE N88-7902, TRANSDUCERS 2 THRU 11.

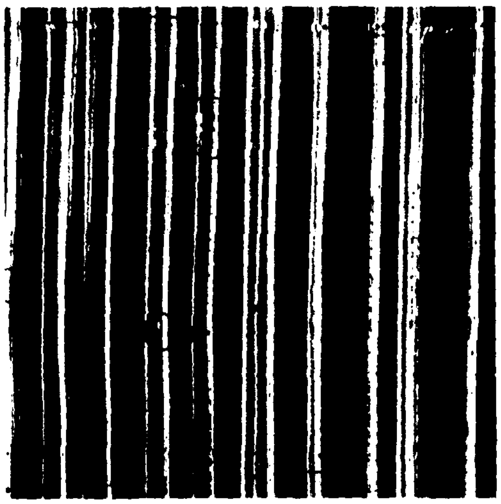


FIGURE 44. FIRST TEST SERIES B SCANS OF TIRE N88-7902, TRANSDUCERS 12 THRU 21.

image is degraded slightly on the facsimile print and further degraded by the photographing and size reduction as presented here. The initial video image is approximately 7 inches high and 9 inches wide.

The scans on Figure 43 are from transducers 2 on the left through 11 on the right; and on Figure 44, are 12 on the left through 21 on the right as numbered on Figure 39 schematic.

The tire dimensions are distorted in this type of display. The top-to-bottom height indicating the circumference scanned and left to right providing an indication of relative section thickness scanned. The distortion of scan circumference is not the same for all transducers; for instance, the number 11 and 12 transducers are scanning near the 34 inch diameter crown center and represent a circumference of 106 inches, while the number 2 and 21 transducers are scanning the lower sidewall at approximately a 23 inch diameter, representing a scan circumference of 72 inches.

Despite the limitations imposed by these compromises, extensive structural information was obtained. A substantial number of the known defects and other structural features lying within the inspected sections of the tires were identified.

Based upon the results of these tests we decided to carry out the second inspection series after the following changes:

- Use 1.0 MHz transducers.
- Have Teknekron modify the time width for the B scan in order to display the entire acoustical path for the relatively thick-wall aircraft tires.
- Time-varied gain was used to increase sensitivity and to enhance the signal for video display.
- Only 15 transducers of the 1.0 MHz type were available. These were arranged so the sidewall opposite the serial side(OSS) was not inspected as shown in Appendix B, Figure 3.

The results, described in detail in Appendix B, were quite good. The reduction in resolution in changing from 2.25 MHz to 1.0 MHz did not significantly reduce detectability of flaws,and the lower frequency plus time-varied gains allowed acceptable penetration.

The B scan width for the second inspection series was approximately 2 inches wide for each channel, permitting showing only four channels simultaneously on the video screen. Analysis was done primarily using the fascimile copies laid out side by side for the whole tire area scanned. These fascimile copies permit analysis without tying up the inspection equipment electronics,and serve as a part of the inspection record.

3.5.6 NEW DEVELOPMENT IN ULTRASONIC INSPECTION

Possible improvements toward a production inspection system based on the DOT system design are discussed by Morris Ho of Teknekron, Inc. in Appendix A.

There is also a possibility that some electronic gate techniques could enable the video display of only anomalous areas, thereby simplifying analysis by eliminating spurious signals.

3.6 X-RAY INSPECTION METHOD

3.6.1 GENERAL

X-ray inspection of tires has been in widespread use for a number of years, but not for the purpose of qualifying commercial carrier aircraft tires for retreading. Most x-ray tire inspection systems of recent design do not use film to record the tire image; instead, a video image of a fluoroscope screen is provided for direct observation by an inspector-operator.

3.6.2 SOURCES OF INFORMATION AND INSPECTION

Most x-ray inspection systems in use for aircraft tires are of a "Universal Type" that will accept a wide variety of sizes for autos, trucks, or aircraft. The principal domestic manufacturers were Westinghouse, Picker Corporation, Imagex, INc., and Monsanto Company.

At the time this evaluation study was soliciting inspection sources, Westinghouse was no longer offering tire inspection equipment nor was Picker Corporation. Monsanto Company had purchased the Picker Corporation interests in the tire x-ray field and Monsanto was providing parts and service for equipment of Westinghouse and Picker manufacture which is in use.

Arrangements were made for inspection of the eight aircraft test tires at Imagex, Inc. and at Monsanto Company. Early in the program Imagex went out of business and it was decided that BFGoodrich, Akron, Ohio would be used as an inspection source in addition to Monsanto Company. Two separate inspections of the evaluation tires(before and after air needle inspection of the new tires) were done at each facility.

At BFGoodrich the same inspection equipment of Westinghouse manufacture was used for both inspections. This equipment closely resembles the Monsanto Universal X-Ray System. This inspection was performed by a technician regularly assigned as the x-ray system operator/inspector with the author of this report observing all inspection.

The two separate inspections at Monsanto Company, Rubber Testing Instrument Division, Akron, Ohio were done on two different systems by Mr. Ted Neuhaus of Monsanto Company with Mr. D. Ewing, the author of this report, observing. The first

inspection series was done on a Monsanto Company Model 10/27/750 Tire Testing Instrument, which has many automated features. The second inspection was on a Monsanto Universal X-Ray System.

Mr. Ted Neuhaus of Monsanto Company provided the equipment state-of-the-art information and cost information used in this report. Estimates of tire handling rate and defect detection capability are our own, based on the observed inspection procedure and results, and on past in-house experience.

3.6.3 DESCRIPTION OF X-RAY SYSTEM EQUIPMENT

The Westinghouse equipment at BFGoodrich, although an older model, is almost identical with the Monsanto Universal System and will not be described separately.

The Monsanto Universal System is, in our opinion, the basic unit which a tire retreader would need. The system includes two air conditioned enclosures: a radiation enclosure which houses the tire manipulator and drive, the x-ray source, generator and cooling system, and the imaging system; an operator enclosure which houses the system controls and the video display which the operator views during inspection. The two enclosures are joined as shown in Figure 45. A radiation protective window is provided adjacent to the console so the operator has a direct view of the tire manipulation during testing.

The inspection equipment inside the radiation enclosure includes the following principal components shown in Figure 46:

- Monsanto patented Lighthouse X-Ray Tube on a servo-controlled manipulator device. This tube is small enough to enter most spread tire sections where it provides consistent geometrical presentations from sidewall to sidewall.
- X-Ray generator and control, and cooler.
- Fluoroscopic imaging system with isocon television camera, and a manipulator for moving the imaging system around the tire section in a horizontal plane.
- A tire manipulator including four bead spreader/rotating spindles to provide stable rotation. Tires must be manually loaded onto and off of spindles.
- Air conditioning system for consoles.
- Motorized radiation console door with safety interlocks, time delay alarm, and warning lights to prevent initiation of radiation unless enclosure is closed and tire handler has exited.

The air conditioned operator console (the light colored console on Figure 45) includes the following principal components:

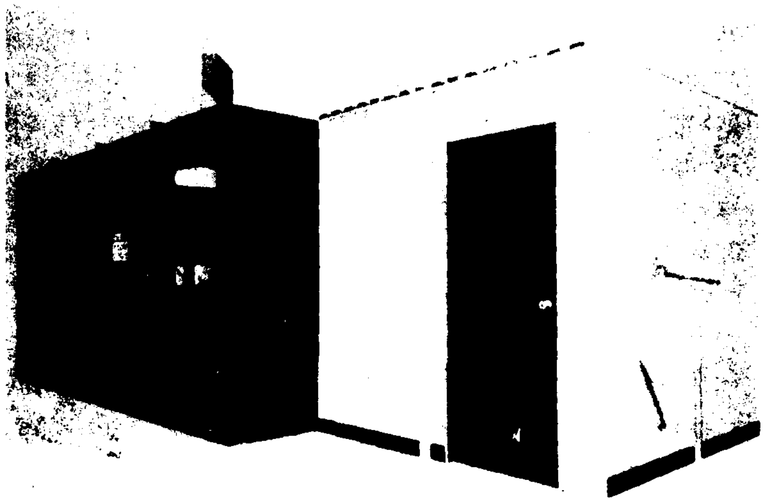


FIGURE 45. MONSANTO UNIVERSAL X-RAY SYSTEM ENCLOSURES.

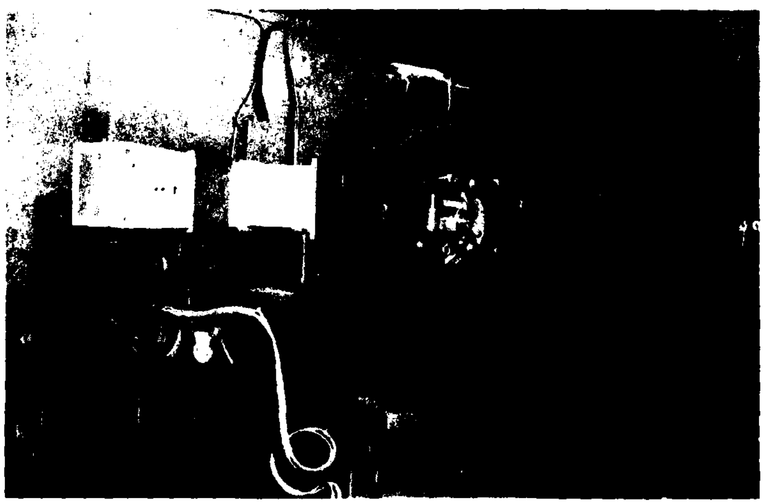


FIGURE 46. MONSANTO UNIVERSAL X-RAY SYSTEM TIRE MANIPULATOR, X-RAY TUBE, AND IMAGING SYSTEM.

- Operator control console with writing desk and television display. This console provides all controls for gripping and spreading the tire, positioning the x-ray tube and the fluoroscopic imaging system, and controlling tire rotation. It also includes television picture adjustments including magnification. The console display closely resembles two dark colored cabinets on the left side of Figure 47. It does not include the lower row of push buttons which are used to key data into the computer storage.
- Operator's seating with convenient viewing window into the radiation enclosure. Selectively dimmed lights in the operator enclosure enhance the television picture contrast and prevent reflections in the window to the lighted radiation enclosure.

It is estimated that a careful bead-to-bead inspection of aircraft tires could be done at the rate of 40 to 50 per 8 hour shift using two operators: a console operator/inspector,and a tire handler for loading tires. The tire handler will have time for other duties such as trucking while a tire inspection is in process.

Inspection results are usually manually noted on an inspection form by the console operator. A video tape recorder can be attached for selectively recording television images.

The Monsanto 10/27/750 X-Ray System includes the major components of the Universal X-Ray System but it has many automated features. The model number designation indicates this system's capability to inspect intermixed tires of bead diameter range 10 inches to 27 inches diameter and of weights to 750 pounds. The system provides the following equipment and operational feature differences from the Universal System:

- There is no need for a tire handler to enter the radiation enclosure. The tires are conveyed or loaded horizontal onto a roller conveyor outside the radiation enclosure, Figure 48. After inspection,the tires are automatically ejected from a door on the opposite side of the radiation enclosure. Handling of ejected tires away from the enclosure is at the option of the user. When the console operator initiates entry of a tire, positioning guides automatically center the tire on the feed system and sense its diameter and thickness. This size information centers the tires over the eight vertically oriented spreader/rotator spindles controlling their contact and spreading, and automatically positions the Lighthouse x-ray tube inside the tire's spread section. The tires remain horizontal throughout the inspection

procedure. When inspection is complete, at the operator's signal the spindles withdraw and the tire is conveyed out of the enclosure. The entry and exit doors include safety switches which prevent x-ray actuation unless the doors are closed. Figure 49 is a view into the interior through the exit door with a tire in inspection position and a tire ready to enter through the open entry door in the background.

- The operator control console(Figure 47) includes a solid state process controller which can automatically control tread, bead, and sidewall x-ray geometry viewing for each tire size and construction, including: x-ray tube position, imaging system positioning, tire rotation and speed. Manual override of the automatic control or complete manual operation is provided. The controller can interface with an information storage system. In Figure 47 the process controller cabinet is on the right.
- Self-diagnostic signals for the mechanical and electronic systems are provided for malfunction alert and location.

This automatic system could speed up the inspection rate to approximately double that of a Universal System and, with feed and removal conveyors, may only require one operator.

3.6.4 COST OF X-RAY EQUIPMENT AND OPERATION

The Monsanto Univeral X-Ray System is representative of a basic tire inspection unit for a retreader. Its cost(1978 dollars) is $132,000 with an additional $5,000 for installation.

The automatic 10/27/750 System cost is $276,000 with $10,000 additional for installation. This unit is very nearly double the cost of a Universal System but would require fewer man-hours for operation and should provide nearly double the throughput.

A video tape recorder would be an optional equipment addition at approximately $1,500.

Routine maintenance costs are estimated at $5,000 for the Universal and $10,000 for the automatic system. This expense includes a new x-ray tube annually.

Utility services requirements should present no problem in a tire retread shop.

Environmental protection and operator safety are provided in the system. Operators would have to wear radiation exposure badges as wouldother personnel reguarly stationed nearby.

FIGURE 47. MONSANTO 10/27/750 X-RAY SYSTEM OPERATOR CONSOLE.

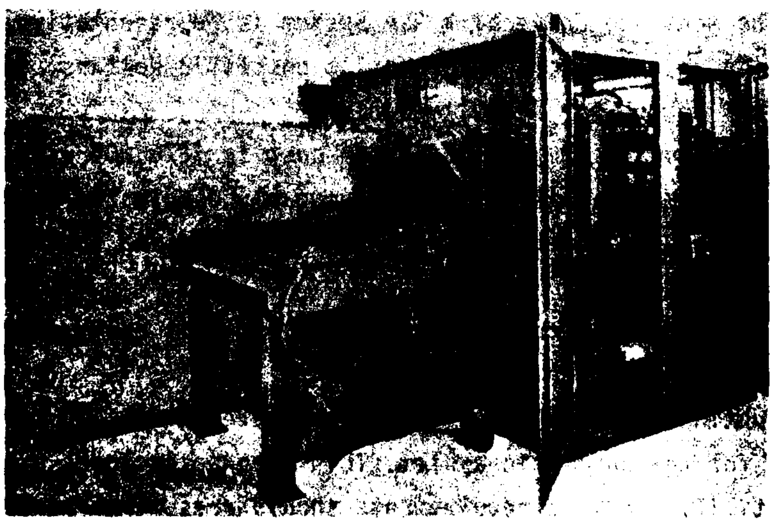


FIGURE 48. MONSANTO 10/27/750 X-RAY SYSTEM FEED CONVEYOR. MAINTENANCE DOORS ARE OPEN IN RADIATION ENCLOSURE.

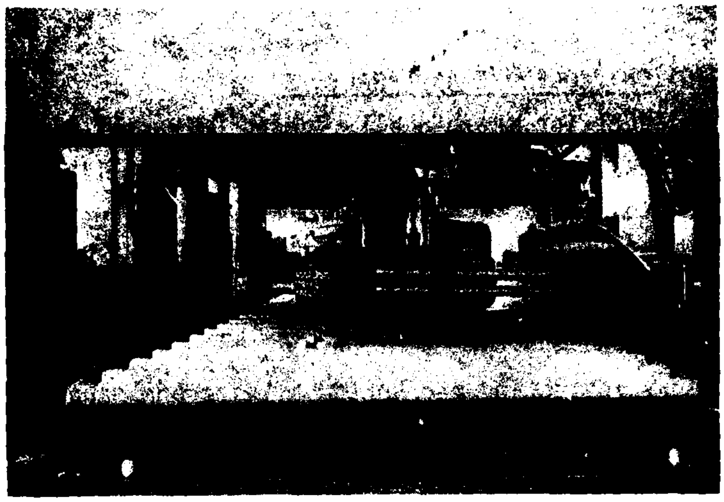


FIGURE 49. MONSANTO 10/27/750 X-RAY SYSTEM. INTERIOR VIEW FROM EXIT SIDE.

A one week training course for equipment operators at Monsanto Company's Akron, Ohio plant facility is included in the purchase price of equipment. The only cost involved to an operator would be transportation and living expenses. An operator/inspector should have a knowledge of tire construction such as a tire builder.

3.6.5 X-RAY INSPECTION PROCEDURE AND ANALYSIS

Only the procedure for the manually loaded Universal X-Ray System is described here. The Westinghouse System at BFGoodrich utilizes identical procedure. The automatic Monsanto System is essentially the same except for the automatic load/unload capability,and the capability for automatic repositioning of x-ray tube and imaging system and tire rotational speed control as increments of surface area are inspected around the tire section.

Tires for x-ray inspection are sorted by size and manufacturer so the operator can minimize the need for revised mental space orientation in viewing the video images of the tires.

To start the inspection, the door to the radiation enclosure is opened and a tire is moved into the enclosure and lifted onto the manipulator spindles,making sure the spindle flanges, which engage the bead toes for spreading, are inside the beads. A tire lifting hoist would be useful for aircraft tires which are too heavy and unwieldy for handling by a single man. Spindle radial motion and flange extension to spread the tire is actuated by the tire handler by controls inside the radiation enclosure(he cannot actuate x-radiation). He can observe the position of the tire on the spindles from his close vantage pointand make needed readjustments while still in the enclosure.

When he is satisfied that the tire is properly seated and spread, he marks a zero degree chalk mark on the tire sidewall and he leaves the enclosure taking with him the tire previously inspected. When the tire handler leaves, the door is shut,completing the radiation enclosure and closing the safety switches permitting control by the console operator.

The console operator positions the x-ray tube inside the spread tire section, approximately between the spread beads, and positions the imaging system for the area of inspection he intends to view. This is done by direct observation through the viewing window and then fine adjustments are made to optimize the video image.

When the video image is sharply defined, tire rotation is initiated and the ring shaped area of the tire which is imaged is viewed on the video screen. A 3 to 5 inch band of surface area is inspected dependingon the magnification selected. After rotating 360°, as estimated by viewing the chalk stripe on the

tire sidewall, the imaging system is moved to view the next increment of tire surface and the inspection process is repeated; and so forth, until the entire tire surface to be inspected is viewed. The console operator can slow, stop, or reverse tire rotation and can alter magnification to a limited extent to view areas of interest.

Defects located are normally described by manual notation on an inspection form sheet. In this evaluation, a holographic inspection form was used to note location of defects, as estimated from the observed angular rotation of the 0^{o} chalk mark, and the position of the imaging system with respect to the tire section.

The clarity of the television image, the contrast, and brightness is an important factor in searching for defects.

In analyzing anomalous areas in the construction, a knowledge of tire construction is needed. Anomalies usually appear as areas of subtly greater brightness than the surrounding area of similar construction for a surface gouge or for some separations. The x-ray detects the tire construction components by their relative transparency to radiation. For a many-plied aircraft tire, a flaw in a single ply causes a relatively small difference in overall x-ray transparency that is difficult to detect. In auto tires which may have only two carcass plies, the relative difference caused by a flaw is greater and easier to see on the video display. Separations or unbonds which develop in service may not represent any difference in material thickness or x-ray transparency and may not be detected. Metal layers such as bead wire bundles or, in an auto or truck tire, wire belt plies, are considerably less transparent to x-radiation than fabric and rubber,and contrast very distinctly on the video display.

Bright areas may be caused by surface gouges or by voids in the construction. The exact nature of the cause can only be deduced by relating the shape and position to known construction features.

In tires with multiple bead wire bundles, one bundle screens the x-ray penetration from the others and unless there are wild wires significantly departing from the bundles they are difficult to view - the center bundle of a three-bundle bead, as in the test tires, is virtually impossible to scan.

Following are four photographs taken during the inspection of test tires on the Monsanto Universal System. These were taken with a shrouded, hand held Polaroid camera available as optional equipment from Monsanto. The camera shroud cone is placed against the video screen cover glass which provides a fixed object distance, and the camera is triggered.

FIGURE 50. SLIGHTLY SEPARATED BEAD WIRE LAYER IN NO. 3 BEAD ON TIRE N88-7899.

FIGURE 51. CUT IN UPPER SIDEWALL OF TIRE NO. N66-0773,#2.

FIGURE 52. LINER GOUGE IN TIRE NO. N66-0773,#3.

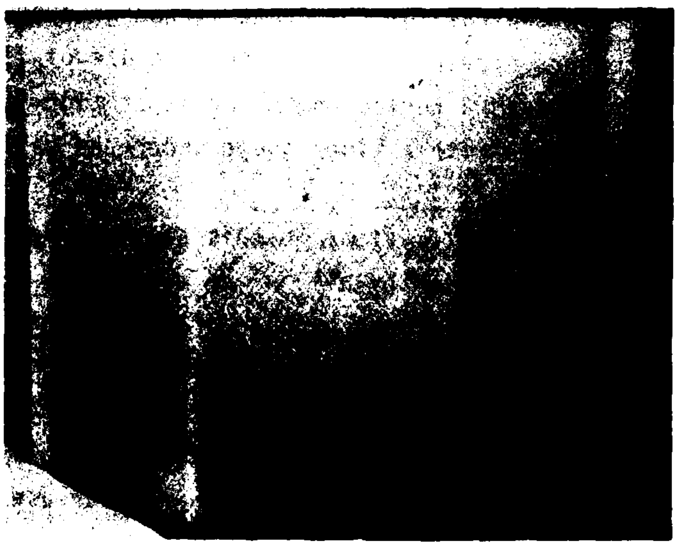


FIGURE 53. OLD LINER REPAIR PATCH OVER LINER GOUGE IN TIRE NO. N66-0773,#4.

Thephotographs are more limited in extent than the video image and the quality has suffered in the photographic process.

Figure 50 is a view of the No. 3 bead in test tire No. N88-7899 showing some separation of the last bead wire layer from the bundle, a built-in defect which probably would not be reason to reject the tire.

Figure 51 shows a cut resembling a backward letter "C" to the right of the photograph. This is located high on the SS sidewall near the series of annular rings(visible to the left of the cut) which mark the blend of shoulder and sidewall rubber at the last retread. The relative absence of cords crossing the cut indicates that it is nearly through the entire carcass. The light vertical bar at the left is a tread groove. This defect was on tire No. N66-0773#2 at approximately 315^{0} rotation.

Figure 52 is a view of tire N66-0773#3 at approximately 270^{0} rotation, SS. At the left of the photograph is a light area approximately 2 inches long and 1/4 to 1/2 inch wide following one of the cord ply bias directions. This could be a separation or a surface defect. Direct visual inspection indicated this was a gouge in the liner.

Figure 53 is a view of tire N66-0773#4 at approximately 180^{0} rotation near crown center. The tread on this R5 tire is nearly obliterated by partial buffing; hence, the relative low contrast of the center tread grooves. The transverse line with rounded corners appears to be a patch because of its geometry. The bright bias line at lower center is a surface gouge or separation. Direct surface inspection revealed an old liner patch with a liner gouge under the patch.

3.7 TIRES FOR INSPECTION TESTING

In order to evaluate test systems in this program a group of eight aircraft tires was provided for inspection by all.

Tires of size 34X11 were chosen because of size restrictions of the ultrasonic test system at DOT, one of the inspection sources which indicated willingness to participate. These were 22 ply rating, Type VII-Extra High Pressure tires typical of tires in universal service on today's military and civilian jet and prop-jet aircraft. This tire size is in regular use on auxiliary(nose) gear on DC-8 aircraft.

These tires have 14 carcass plies, three bead wire bundles in each bead, and two chafer strips. The new tires were built with 3 fabric tread reinforcement (inserts) plies; whereas the retreaded tires had 2 insert plies.

A group of retreaded 34X11 tires which had been rejected at BFGoodrich retread facilities was returned to Akron. Four test tires were selected from this group after direct visual and air needle inspection to determine what kinds of defects were exhibited in these tires. All these tires had been retreaded previously, from one to seven times. All of the tire defects or anomalies consistently detected were recorded and are listed on the inspection results tables in the following report section 3.8. Ultrasonic testing at DOT indicated some "singularities" or "anomalies" which could not be identified in these tires and which are not listed.

Four new tires were produced with built-in defects, some of which would not be cause for rejection of a tire but were included to evaluate the NDT inspection system's abilities for their detection.

These included the following separations or unbonds produced by circular disks of 1 mil thick plastic release film inserted during the tire building operation. Each type of separation was produced in three sizes by plastic disks of 1/4 inch, 1/2 inch, and 1 inch diameters:

- Liner blisters(between liner and 1st ply).
- Separations under the finishing strip under the annular rings on the lower sidewall.
- Ply turnup separation.
- Separation between #3 insert and tread.
- Mid-carcass shoulder separation.

The following separations were induced between two inside plies and between two outside plies in addition to being induced in three diameter sizes:

- Mid-sidewall separations.
- Shoulder separations.
- Crown separations.
- Bead area ply separations(2 inches above toe).

In addition to the separations, the following defects were built into the tires:

- Ply splices grouped in one quadrant(normally ply splices are distributed around the tire) - a potential balance problem.
- Wide liner splice.
- Wide insert splices.
- Open insert splices.
- Loose bead wire layer(induced by stripping rubber coating from wire near outer end of bundle).

The specific tire in which these defects are located and their locations on the tires are indicated on the inspection results tables in report section 3.8. Some additional liner and bead area defects were inflicted on these tires during shipment handling. These are also listed. As with the used tires, the DOT ultrasonic inspection indicated some "anomalies" and "singularities" in the new tire construction which could not be identified and are not listed.

The four new tires were each subjected to four 210 mile per hour take off cycles on a dynamometer,with simulated service loadings to flex the tires to enhance separation of the built-in unbonded areas and to break-in the carcass, eliminating the as-vulcanized set or inflexibility of the carcass laminate.

3.8 INSPECTION RESULTS

The eight 34X11 aircraft tires were inspected twice by each inspection method except the air needle buffing method which was done only once and which was done last, since it included buffing off the tread and shoulder rubber as would be done in preparation for retreading.

The inspections were all observed by either Mr. S. Caprette(ultrasonic testing at DOT) or by Mr. D. Ewing, except for the NRC holographic testing which was done at an army base in Yuma, Arizona where attendance by an observer couldn't be arranged.

The inspections were done "blind"; i.e., the inspector or analyst did not know the nature or location of tire defects except those that were detectable by his direct visual inspection of the tires. After the second inspection analysis the inspectors were provided with a list of defects for each tire.

Rotational angle orientation errors were evident in describing defect location. This was because of some inherent lack of precision in orienting tires and, in two cases, mounting tires wrong side out on the inspection apparatus. This was important only because it made comparison between test methods more difficult.

Holographic inspection record forms were used to indicate the angular orientation and location on the tire section of discovered defects for the x-ray inspections, the air needle inspection, the air needle buffing inspection, and, of course, the holographic inspections. Such specific location notation is not customarily done except for holographic inspection and such forms were not available.

For the ultrasonic second inspection at DOT, transparent overlays dimensionally oriented to the first ultrasonic B scan video display were provided with defects (appropriately dimensionally adjusted) indicated on the transparencies. These were intended as an aid in locating defects on the second inspection video displays and included only those defects deemed detectable using the first inspection

transducer arrangement(bead area and lower sidewall defects were omitted). The second inspection transducer arrangement was different and the video B scan presentation was different so these transparencies were not effective as overlays. Mr. Bobo of DOT, who analyzed the inspection results,referred to the defect markings on these overlays in describing the effectiveness of this inspection system in Appendix B. Small scale photographs of those overlays are included in his report, Appendix B.

The tires were inspected in the order shown on Table 1. In tabulating the detection capabilities, the second inspection results by each test facility were used except for the air needle buffing method which was done only once. There was little difference between first and second inspections except that some liner and bead surface damage was incurred during tire shipment handling(deduced to be caused by lift truck forks inserted inside tires) which was evident in second inspections and not in the first.

NRC detected some difference in holographic fringes between their first and second inspections which they attribute to air needle injection damage. They did not, however, detect an increase in separation size,which was a criterion for investigation. Separation size can't be measured with precision in any of these methods because of test variables.

The inspection results by each method are tabulated for each tire on Tables 2 through 9. Also tabulated are the defects discovered by direct visual inspection of the outside surface and the bead surfaces of the tires. Each defect is described for each tire in terms of: type and size of defect; location on tire in terms of rotation angle and position on the section; and location within the carcass laminate. Each inspection method is indicated for its ability to detect each of those defect characteristics; although it is true that describing the location of a detected defect in rotation or in the tire section depends on the establishment of an orientation system between the tire and the inspection equipment or the observer, and is subject to considerable error in measurement or estimation.

On those tables where the defect was located outside the scan area of the system the table is marked "N/A" for "Not Applicable". Where location in the laminate is indicated as "APP" for "Approximate", the method could not indicate precisely between which plies the defect was located, but it did give an indication of: between inner plies, between outer plies, or between mid-carcass plies.

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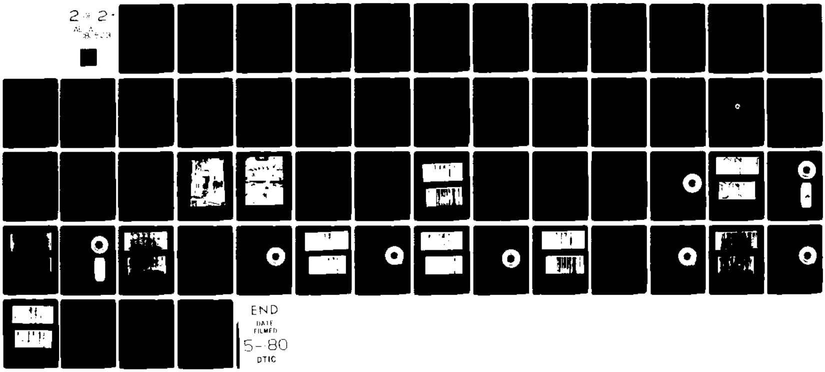

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TABLE 1. ORDER OF INSPECTION OF TEST TIRES

INSPECTION ORDER	INSPECTION TYPE	INSPECTION SOURCE
1	X-Ray	Monsanto Company, Akron, Ohio
2	Ultrasonic	DOT, Transportation Systems Center, Cambridge, Massachusetts
3	Holographic	Newport Research Corp., (NRC) Fountain Valley, California
4	X-Ray	BFGoodrich Tire Division, Akron, Ohio
5	Holographic	BFGoodrich Tire Division, Akron, Ohio
6	Air Needle	BFGoodrich Tire Division, Akron, Ohio
7	Holographic	BFGoodrich Tire Division, Akron, Ohio
8	X-Ray	Monsanto Company, Akron, Ohio
9	Ultrasonic	DOT, TSC, Cambridge, Massachusetts
10	Holographic	NRC, Fountain Valley, California
11	X-Ray	BFGoodrich, Akron, Ohio
12	Direct Visual	BFGoodrich Retread Center, Montreal, Quebec
13	Air Needle	BFGoodrich Retread Center, Montreal, Quebec
14	Air Needle Buffing	BFGoodrich Retread Center, Montreal, Quebec

TABLE 2. DEFECT DETECTION - NEW TIRE NO. N88-7899

Detection by NDT Method

Defect Description Location Depth in Laminate	Visual Outside	Air Needle	X-Ray BFG	X-Ray Monsanto	Sonic DOT	Holo BFG	Holo NRC	Air Needle Buff BFG
1. 1/4" Dia.Ply Separation	No	No	No	No	N/A	N/A	N/A	N/A
3" above bead, 2°, OSS	No	No	No	No	N/A	N/A	N/A	N/A
Under outer ply turnup,3rd bead	No	No	No	No	N/A	N/A	N/A	N/A
2. 1/2" Dia.Ply Separation	No	No	No	No	N/A	N/A	N/A	N/A
2" above bead, 88°, SS	No	No	No	No	N/A	N/A	N/A	N/A
Between 8 & 9 plies	No	No	No	No	N/A	N/A	N/A	N/A
3. 1" Dia.Ply Separation	No	Yes	No	No	Yes	Yes	Yes	N/A
Mid sidewall, 88°, OSS	No	Yes	No	No	Yes	Yes	Yes	N/A
Between 1 & 2 plies	No	App	No	No	Yes	App	App	N/A
4. 1" Dia.Ply Separation	No	No	No	No	Yes	N/A	Yes	N/A
Mid sidewall, 177°, SS	No	No	No	No	Yes	N/A	Yes	N/A
Between 12 & 13 plies	No	No	No	No	Yes	N/A	App	N/A
5. Loose bead wire layer	No	No	Yes	Yes	N/A	N/A	N/A	N/A
#3 bead, 140°-178°, SS	No	No	Yes	Yes	N/A	N/A	N/A	N/A
Outer wrap on #3 bead	No	No	App	App	N/A	N/A	N/A	N/A
6. 1/2" Dia.Ply Separation	No	No	No	Yes	Yes	N/A	N/A	N/A
Mid sidewall, 194°, SS	No	No	No	Yes	Yes	N/A	N/A	N/A
Between 13 & 14 plies	No	No	No	No	Yes	N/A	N/A	N/A
7. 1/4" Dia.Ply Separation	No	No	No	No	Yes	Yes	N/A	N/A
Mid Sidewall, 282°, SS	No	No	No	No	Yes	Yes	N/A	N/A
Between 13 & 14 plies	No	No	No	No	Yes	App	N/A	N/A
8. Splices stacked	No	No	No	No	No	No	No	No
0°-90°, 1st quadrant	No	No	No	No	No	No	No	No
All plies	No	No	No	No	No	No	No	No
9. Splices crossed in ply pairs	No	No	No	No	No	No	No	No
0°-90°, 1st quadrant	No	No	No	No	No	No	No	No
All plies	No	No	No	No	No	No	No	No
10. Liner Crack(non leaking)	Yes	Yes	No	No	N/A	N/A	N/A	N/A
SS, 0°-160°, at bead toe.	Yes	Yes	No	No	N/A	N/A	N/A	N/A
Liner	Yes	Yes	No	No	N/A	N/A	N/A	N/A
11. 1" Dia.Ply Separation	No	Yes	No	No	N/A	N/A	N/A	N/A
2" Above bead, 180°, OSS	No	Yes	No	No	N/A	N/A	N/A	N/A
Inside Turnup	No	App	No	No	N/A	N/A	N/A	N/A

TABLE 3. DEFECT DETECTION - NEW TIRE NO. N88-7900

Detection by NDT Method

Defect Description Location Depth in Laminate	Visual Outside	Air Needle	X-Ray BFG	X-Ray Monsanto	Sonic DOT	Holo BFG	Holo NRC	Air Needle Buff BFG
1. 1" Dia. liner blister	No	Yes	No	No	No	Yes	Yes	No
2°, CC	No	Yes	No	No	No	Yes	Yes	No
Between liner & 1st ply	No	Yes	No	No	No	App	App	No
2. 1/2" Dia.Ply separation	No	Yes	No	No	No	No	Yes	No
2" from CC, 3°, SS	No	Yes	No	No	No	No	Yes	No
Between 1 & 2 plies	No	App	No	No	No	No	App	No
3. 1/4" Open insert splice	No	No	No	No	No	No	No	No
75°, crown	No	No	No	No	No	No	No	No
#2 insert	No	No	No	No	No	No	No	No
4. 1/4" Dia. separation	No	No	No	No	Yes	Yes	Yes	No
Shoulder,90°,OSS 4" from CC	No	No	No	No	Yes	Yes	Yes	No
Between 1 & 2 plies	No	No	No	No	App	App	App	No
5. 1/2" Dia. liner blister	No	Yes	No	No	N/A	Yes	Yes	N/A
Mid sidewall, 92°, OSS	No	Yes	No	No	N/A	Yes	Yes	N/A
Between liner & 1st ply	No	Yes	No	No	N/A	App	App	N/A
6. 1/4" Open insert splice	No	No	No	No	Yes	No	No	Yes
150°, crown	No	No	No	No	Yes	No	No	Yes
#3 insert	No	No	No	No	App	No	No	App
7. 1/4" Dia. liner blister	No	Yes	No	No	No	Yes	Yes	N/A
Mid sidewall, 183°, SS	No	Yes	No	No	No	Yes	Yes	N/A
Between line & 1st ply	No	Yes	No	No	No	App	App	N/A
8. 1" Dia. Ply Separation	No	No	No	No	Yes	Yes	Yes	No
225°, CC	No	No	No	No	Yes	Yes	Yes	No
Between 13 & 14 plies	No	No	No	No	Yes	App	App	No
9. 1/4" Dia. Ply Separation	No	Yes	No	No	No	Yes	Yes	No
265°, CC	No	Yes	No	No	No	Yes	Yes	No
Between 1 & 2 plies	No	App	No	No	No	App	App	No
10. 1/2" Dia. Separation	No	No	No	No	Yes	Yes	Yes	No
Shoulder, 286°, SS	No	No	No	No	Yes	Yes	Yes	No
Between 13 & 14 plies	No	No	No	No	App	App	App	No
11. 1/4" Open insert splice	No	No	No	No	No	No	No	No
355°, crown	No	No	No	No	No	No	No	No
#1 insert	No	No	No	No	No	No	No	No

TABLE 4. DEFECT DETECTION - NEW TIRE NO. N88-7901

Detection by NDT Method

Defect Description Location Depth in Laminate	Visual Outside	Air Needle	X-Ray BFG	X-Ray Monsanto	Sonic DOT	Holo BFG	Holo NRC	Air Needle Buff BFG
1. 1" Dia. Separation	No	No	No	No	Yes	N/A	N/A	N/A
Under annular rings, 2°,SS	No	No	No	No	Yes	N/A	N/A	N/A
Under #2 finish strip	No	No	No	No	App	N/A	N/A	N/A
2. 1" Insert splice	No	No	No	No	Yes	No	No	No
5°, crown	No	No	No	No	Yes	No	No	No
#3 insert	No	No	No	No	Yes	No	No	No
3. 1" Insert splice	No	No	No	No	Yes	No	No	No
62°, crown	No	No	No	No	Yes	No	No	No
#1 insert	No	No	No	No	Yes	No	No	No
4. 1/4" Dia. Separation	No	No	No	No	Yes	Yes	Yes	No
Shoulder, 130°, OSS	No	No	No	No	Yes	Yes	Yes	No
Between 9 & 10 plies	No	No	No	No	App	App	App	No
5. 1/4" Dia. Separation	No	No	No	No	N/A	N/A	N/A	N/A
Under annular rings, 179°, OSS	No	No	No	No	N/A	N/A	N/A	N/A
Under #2 finish strip	No	No	No	No	N/A	N/A	N/A	N/A
6. 1/2" Dia. Separation	No	No	No	No	Yes	Yes	Yes	Yes
Shoulder, 225°, OSS	No	No	No	No	Yes	Yes	Yes	Yes
Between 9 & 10 plies	No	No	No	No	App	App	App	App
7. 1" Insert splice	No	No	No	No	Yes	No	No	Yes
258°, Crown	No	No	No	No	Yes	No	No	Yes
#2 Insert	No	No	No	No	Yes	No	No	App
8. 1/2" Dia. Separation	No	No	No	No	Yes	N/A	N/A	N/A
Under annular rings, 269°, SS	No	No	No	No	Yes	N/A	N/A	N/A
Under #2 finish strip	No	No	No	No	App	N/A	N/A	N/A
9. 1" Dia. Separation	No	Yes	No	No	Yes	Yes	Yes	No
Shoulder 315°, SS	No	Yes	No	No	Yes	Yes	Yes	No
Between 9 & 10 plies	No	No	No	No	Yes	App	App	No
10. 1-1/4" wide liner splice	No	Yes	No	No	Yes	Yes	Yes	No
Bead to bead, 342° at CC	No	Yes	No	No	Yes	Yes	Yes	No
liner	No	Yes	No	No	Yes	Yes	Yes	No
11. 1/2" Dia. air blister	No	No	No	No	Yes	Yes	No	No
Shoulder, 347°, SS	No	No	No	No	Yes	Yes	No	No
In liner splice	No	No	No	No	Yes	App	No	No

TABLE 5. DEFECT DETECTION - NEW TIRE NO. N88-7902

Defect Description Location Depth in Laminate	Detection by NDT Method Visual Outside	Air Needle	X-Ray BFG	X-Ray Monsanto	Sonic DOT	Holo BFG	Holo NRC	Air Needle Buff BFG
1. 1/2" Dia. Separation	No	Yes	No	No	No	Yes	Yes	No
0°,CC	No	Yes	No	No	No	Yes	Yes	No
Between 1 & 2 plies	No	App	No	No	No	App	App	No
2. 1/4" Dia. Separation	No	No	No	No	No	No	No	Yes
2" from CC, 0°,OSS	No	No	No	No	No	No	No	YES
Between tread & inserts	No	No	No	No	No	No	No	Yes
3. 1/4" Dia. Separation	No	No	No	No	N/A	N/A	N/A	N/A
1" above bead toe,89°,SS	No	No	No	No	N/A	N/A	N/A	N/A
Between 2 & 3 plies	No	No	No	No	N/A	N/A	N/A	N/A
4. 1/2" Dia. Separation	No	No	No	No	No	Yes	Yes	Yes
2" from CC, 90°, OSS	No	No	No	No	No	Yes	Yes	Yes
Between tread & inserts	No	No	No	No	No	App	App	Yes
5. 1/2" X 6" Separation	No	Yes	No	No	N/A	N/A	N/A	N/A
1" above bead toe, 78°,SS	No	Yes	No	No	N/A	N/A	N/A	N/A
Between 6 & 7 plies	No	App	No	No	N/A	N/A	N/A	N/A
6. 1" Dia. Separation	No	No	No	No	Yes	Yes	Yes	Yes
180°,CC	No	No	No	No	Yes	Yes	Yes	Yes
Between tread & inserts	No	No	No	No	Yes	App	App	Yes
7. 1" x 6" Separation	No	Yes	No	No	N/A	N/A	N/A	N/A
1" above bead toe,270°,SS	No	Yes	No	No	N/A	N/A	N/A	N/A
Between 2 & 3 plies	No	Yes	No	No	N/A	N/A	N/A	N/A
8. Loose Liner Splice Edge*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
45°,diag across crown	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
liner	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

*This liner splice edge was dusted during building to prevent adhesion but adhered anyway.

TABLE 6. DEFECT DETECTION - OLD R7 TIRE NO. N66-0773,#2

Detection by NDT Method

Defect Description Location Depth in Laminate	Visual Outside	Air Needle	X-RAY BFG	X-Ray Monsanto	Sonic DOT	Holo BFG	Holo NRC	Air Needle Buff BFG
1. Severe ozone cracking	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A
Both sidewalls	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A
Outside surface	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A
2. Liner gouge(leaking)1/2" x 2"	No	Yes	Yes	Yes	No	No	No	N/A
315°,SS,6" above toe	No	Yes	YEs	Yes	No	No	No	N/A
Liner	No	YEs	No	No	No	No	No	N/A
3. Worn tread to 1/16"	Yes	No	No	No	No	No	No	Yes
Entire circ.,CC grove	Yes	No	No	No	No	No	No	Yes
Outer surface	Yes	No	No	No	No	No	No	Yes
4. Balance pads	No	Yes	Yes	Yes	Yes	Yes	Yes	N/A
10° and 100°,CC	No	Yes	Yes	Yes	Yes	Yes	Yes	N/A
Inside surface	No	Yes	No	No	Yes	Yes	Yes	N/A
5. Liner gouge(non-leaking)1/4"x2"	No	Yes	No	No	No	No	No	N/A
6" above toe,305°,SS near 2 gouge	No	Yes	No	No	No	No	No	N/A
Liner	No	Yes	No	No	No	No	No	N/A
6. Liner gouge(leaking)	Leak? Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A
Bead flat,adj.toe,315°,SS	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A
Bead flat liner	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A
7. Weak splices	No	No	No	Yes	Yes	Yes	Yes	No
Quadrants 1,2,3 Crown & Shoulders	No	No	No	Yes	No	Yes	Yes	No
Unknown	No	No	No	No	No	No	No	No
8. Scattered Air at PTU	No	No	Yes	Yes	Yes	N/A	N/A	N/A
PTU,All quadrants	No	No	Yes	Yes	Part.	N/A	N/A	N/A
Inside ply turnup	No	No	No	No	Part.	N/A	N/A	N/A
9. Separated Outer Bead Wire Layer	No	No	Yes	Yes	N/A	N/A	N/A	N/A
345°-30° & 90°-180°SS,345°-45° OSS	No	No	Yes	Yes	N/A	N/A	N/A	N/A
#1 Bead	No	No	Yes	Yes	N/A	N/A	N/A	N/A
10. Crooked tread	No	No	No	No	No	No	No	Yes
All quadrants, tread	No	No	No	No	No	No	No	Yes
Tread	No	No	No	No	No	No	No	Yes

TABLE 7. DEFECT DETECTION - OLD R6 TIRE NO. N66-0773,#3

Detection by NDT Method

Defect Description Location Depth in Laminate	Visual Outside	Air Needle	X-Ray BFG	X-Ray Monsanto	Sonic DOT	Holo BFG	Holo NRC	Air Needle Buff BFG
1. Ozone checking	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A
Both sidewalls	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A
Outer surface	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A
2. Worn tread	Yes	No	No	Yes	Yes	No	No	Yes
350°-90°,105°-180°,250°,340°,CC	Yes	No	No	Yes	Yes	No	No	Yes
Outer surface to #3 insert	Yes	No	No	Yes	Yes	No	No	Yes
3. Gouge in liner(non-leaking)	No	Yes	Yes	Yes	No	N/A	N/A	N/A
2" long, mid sidewall,270°,SS	No	Yes	Yes	Yes	No	N/A	N/A	N/A
Liner	No	Yes	No	No	No	N/A	N/A	N/A
4. Tread cut 3/8"dp,3/4"lg(non-leak.)	Yes	No	Yes	Yes	Yes	No	No	Yes
1" from CC, 0°,SS	Yes	No	Yes	Yes	Yes	No	No	Yes
Outer surface	Yes	No	No	No	Yes	No	No	Yes
5. Liner Repair Patch(non-leaking)	No	Yes	Yes	Yes	No	No	No	N/A
Shoulder, 190°,OSS	No	Yes	Yes	Yes	No	No	No	N/A
Inside surface	No	Yes	No	No	No	No	No	N/A
6. Liner gouge 1/4"x1"(non-leaking)	No	Yes	Yes	Yes	N/A	N/A	N/A	N/A
105°,OSS, mid sidewall	No	Yes	Yes	Yes	N/A	N/A	N/A	N/A
Liner	No	Yes	No	No	N/A	N/A	N/A	N/A
7. Two adjacent shoulder seps,ea 1"dia.	No	No	No	Yes	No	Yes	Yes	Yes
Shoulder, 0°,OSS	No	No	No	Yes	No	Yes	Yes	Yes
12-14 ply	No	No	No	No	No	App	App	App
8. Shoulder sep.,1/4" dia.	No	No	No	No	No	Yes	No	No
Shoulder, 30°,OSS	No	No	No	No	No	Yes	No	No
12-14 ply	No	No	No	No	No	App	No	No
9. Shoulder sep.,1/2"	No	No	No	No	Yes	Yes	Yes	Yes
Shoulder, 180°,OSS	No	No	No	No	Yes	Yes	Yes	Yes
12-14 ply	No	No	No	No	App	App	App	App
10. Shoulder sep., 1/2"	No	No	No	No	Yes	Yes	Yes	Yes
Shoulder, 195°,SS	No	No	No	No	Yes	Yes	Yes	Yes
12-14 ply	No	No	No	No	App	App	App	App
11. Shoulder sep.,1/2"	No	No	No	Yes	Yes	Yes	Yes	Yes
Shoulder, 270°,SS	No	No	No	Yes	Yes	Yes	Yes	Yes
12-14 ply	No	No	No	No	App	App	App	App
12. Unrepaired cut,1-1/2" long	No	No	No	No	No	No	No	Yes
CC, 215°	No	No	No	No	No	No	No	Yes
Under last retread to #14 ply	No	No	No	No	No	No	No	Yes
13. Distorted	No	No	No	No	No	No	No	Yes
Both sides, 360°	No	No	No	No	No	No	No	Yes
Beads	No	No	No	No	No	No	No	Yes
14. Weak splices	No	No	No	Yes	No	Yes	Yes	No
All quadrants	No	No	No	Yes	No	Yes	Yes	No

TABLE 8. DEFECT DETECTION - OLD R5 TIRE NO. N66-0773, #4

Defect Description Location Depth in Laminate	Visual Outside	Air Needle	X-Ray BFG	X-Ray Monsanto	Sonic DOT	Holo BFG	Holo NRC	Air Needle Buff BFG
	Detection by NDT Method							
1. Buffed Carcass	Yes	Yes	No	No	No	No	No	Yes
Entire crown & shoulder	Yes	Yes	No	No	No	No	No	Yes
Outer surface	Yes	Yes	No	No	No	No	No	Yes
2. Ozone checking	Yes	Yes	No	No	No	No	No	No
Both sidewalls	Yes	Yes	No	No	No	No	No	No
Outer surface	Yes	Yes	No	No	No	No	No	No
3. Bead flat leaks - 5 leaks	No	Yes	No	No	No	No	No	No
Liner 270° on flat	No	Yes	No	No	No	No	No	No
Liner on bead flat	No	Yes	No	No	No	No	No	No
4. Bead toe damage (non leaking)	Yes	Yes	No	No	No	No	No	No
45°-150°, 0°-270°, SS	Yes	Yes	No	No	No	No	No	No
Liner at toe	Yes	Yes	No	No	No	No	No	No
5. Liner repair 2" X 3-1/2"	No	Yes	No	No	Yes	Yes	Yes	No
180°-190°, OSS, 2" from CC	No	Yes	No	No	Yes	Yes	Yes	No
Inside surface	No	Yes	No	No	Yes	Yes	Yes	No
6. Weak ply splices	No	No	No	Yes	No	Yes	Yes	No
All quadrants	No	No	No	Yes	No	Yes	Yes	No
?	No	No	No	No	No	No	No	No
7. Liner Repair 2" X 3"	No	Yes	No	Yes	N/A	N/A	N/A	N/A
Mid sidewall, 60°, OSS	No	Yes	No	Yes	N/A	N/A	N/A	N/A
At liner splice	No	Yes	No	Yes	N/A	N/A	N/A	N/A

TABLE 9. DEFECT DETECTION - OLD R1 TIRE NO. N66-0773,#6

Defect Description Location Depth in Laminate	Detection by NDT Method Visual Outside	Air Needle	X-Ray BFG	X-Ray Monsanto	Sonic DOT	Holo BFG	Holo NRC	Air Needle Buff BFG
1. Liner cut (leaks)	No	Yes	Yes	Yes	Yes	No	No	No
70° OSS, 5" above bead	No	Yes	Yes	Yes	Yes	No	No	No
Inside surface	No	Yes	No	No	Yes	No	No	No
2. Ply separation - 6" long	No	Yes	No	No	Yes	N/A	N/A	No
Edge of F.S., 1-1/2"above toe,								
345°-360°, SS	No	Yes	No	No	App	N/A	N/A	No
Under F.S. inside surface	No	App	No	No	App	N/A	N/A	No
3. Worn tread to 1/32"	Yes	No	No	No	No	No	No	Yes
Entire circ, CC groove	Yes	No	No	No	No	No	No	Yes
Outer surface	Yes	No	No	No	No	No	No	Yes
4. Insert splice worn through	Yes	No	No	Yes	No	No	No	Yes
30°, CC	Yes	No	No	Yes	No	No	No	Yes
Outer tread surface	Yes	No	No	Yes	No	No	No	Yes
5. Wear through tread	Yes	No	No	No	No	No	No	Yes
40°-50°, CC	Yes	No	No	No	No	No	No	Yes
Outer tread surface	Yes	No	No	No	No	No	No	Yes
6. Insert break 3/4" long	Yes	No	No	Yes	No	No	No	Yes
345°, CC	Yes	No	No	Yes	No	No	No	Yes
#2 insert, Outer tread surface	Yes	No	No	Yes	No	No	No	Yes
7. Weak ply splices	No	No	No	Yes	No	Yes	Yes	No
All quadrants	No	No	No	Yes	No	Yes	Yes	No
?	No	No	No	No	No	No	No	No
8. Liner blister - 1/8"	No	Yes	No	No	No	No	No	No
Crown, 300°, 2" OSS	No	Yes	No	No	No	No	No	No
Liner	No	Yes	No	No	No	No	No	No

3.9 DISCUSSION OF EVALUATION RESULTS

The advanced NDT inspection methods do not indicate liner leakage or vent hole function, nor is there a reason to expect that they would from an analysis of their principles of operation.

Tire surface conditions - such as: ozone deterioration, overhead damage, cuts and abrasions - can usually only be detected by direct visual surface inspection.

For these reasons the advanced NDT methods cannot take the place of direct visual inspection and/or air needle inspection in qualifying aircraft tires for retread. It is desirable for economic reasons to call out defective tires by the smallest time investment possible. The direct visual inspection should be done first or in conjunction with an air needle inspection. An early air needle inspection is needed to search for liner leaks which can be repaired and to check the integrity of any earlier repair patches. The advanced NDT methods should then be utilized at some time after these standard inspections.

The holographic inspection method is the only advanced NDT method which has been used on aircraft tires as a routine retread qualification method, and it has been used primarily in a search for separations in the upper sidewalls, shoulders,and crown areas of tires.

The reasons for use of the holographic type inspection method in this manner are several:

- Holographic tire inspection equipment is commercially available and there is available background experience in the method and analysis.
- Ultrasonic aircraft tire inspection equipment for similar area scanning is not commercially available,and associated analysis methods are not well developed.
- X-ray equipment does not effectively locate separations that develop from service fatigue.

Some separations are detected by x-ray methods,but it is the opinion of this author,that those are probably separations that are caused by building mistakes; i.e., built-in voids or blisters that contain air or solvent vapors which do not escape in the tire molding process where these trapped gases are heated and compressed into a pressurized bubble which withstands molding pressures and produces a gas-filled void in the tire so that,at that local area,there is less thickness of rubber; which condition can be detected by the x-ray inspection. Separations or

unbonds that result from fatigue-induced delamination do not present less solid material thickness and remain undetected by x-ray inspection.

Separations are not limited to occurrence in the upper sidewalls, shoulders, and crown regions of a tire but aircraft tire section stiffness, equipment capabilities, and cost considerations have limited the inspection to those areas except for special cases.

In order to compare the capabilities of the different inspection methods for detecting separations and for describing their location within the tire carcass laminate, Tables 10, 11, and 12 were constructed from the Defect Detection Tables in report section 3.8, Tables 2 through 9. On Tables 10, 11, and 12 those defects marked N/A were outside the scan range of the equipment or method. "APP" indicates an approximate indication of separation location depth in the laminate. The fractions indicate the number of separations detected divided by the number within the scan range of the equipment. The "0"(zero) indicates not detected or depth in laminate not indicated.

The holographic method consistently detected the largest portion of separations in sizes as small as 1/4 inch,with the ultrasonic method very nearly as good.

The ultrasonic method gave the best indication of precise depth in the laminate. The holographic method gave only an approximate indication of depth in laminate.

Air needle buffing detected a high fraction of separations located in the outer carcass plies. In the opinion of BFGoodrich tire engineers, most fatigue-induced separations occur in the outer carcass plies, but there is not available any statistical verification of that opinion. If that is true, the air needle buffing method could be effective in finding such separations with the added advantage that separations outboard of the carcass plies would be buffed away or exposed for repair and not cause unnecessary rejection of a tire carcass.

Detected separations outboard of the carcass plies, which would be buffed out or repaired in the retreading process, and liner blisters, which could be repaired, may not be precisely located from inspection analysis. In order to avoid unnecessary carcass rejection, the advanced NDT inspection methods should be applied after air needling and buffing.

The next question is "When after buffing?" This may depend on how many times the advanced NDT system could be performed during a single retread process. This, in turn, depends on the associated cost and its acceptance by a customer.

TABLE 10

DETECTION OF 1/4 INCH DIAMETER SEPARATIONS

DEFECT LOCATION	INSPECTION METHOD								
LOCATION IN SECTION / LOCATION IN LAMINATE	NUMBER OF DEFECTS	VISUAL (OUTSIDE ONLY)	AIR NEEDLE (INSIDE)	AIR NEEDLE BUFF (OUTSIDE)	HOLO BFG	HOLO NRC	SONIC DOT	X-RAY BFG	X-RAY MONSANTO
CROWN	1	0	YES	0	YES	YES	0	0	0
BETWEEN 1 & 2 PLY		0	APP	0	APP	APP	0	0	0
CROWN	1	0	0	YES	0	0	0	0	0
BETWEEN TREAD & INSERTS		0	0	YES	0	0	0	0	0
SHOULDER	1	0	0	0	YES	YES	YES	0	0
BETWEEN 1 & 2 PLY		0	0	0	APP	APP	APP	0	0
SHOULDER	1	0	0	0	YES	YES	YES	0	0
BETWEEN 9 & 10 PLY		0	0	0	APP	APP	APP	0	0
SHOULDER	1	0	0	0	YES	0	0	0	0
BETWEEN 13 & 14 PLY		0	0	0	APP	0	0	0	0
MID SIDEWALL	1	0	YES	NA	YES	YES	0	0	0
BETWEEN LINER & 1ST PLY		0	YES	NA	APP	APP	0	0	0
MID SIDEWALL	1	0	0	NA	YES	NA	YES	0	0
BETWEEN 13 & 14 PLY		0	0	NA	APP	NA	YES	0	0
SIDEWALL UNDER ANNULAR RINGS	1	0	0	NA	NA	NA	NA	0	0
UNDER #2 FINISH STRIP		0	0	NA	NA	NA	NA	0	0
BEAD STACK UNDER TURN-UP	1	0	0	NA	NA	NA	NA	0	0
UNDER PLY TURN-UP 3RD BEAD		0	0	NA	NA	NA	NA	0	0
BEAD 2" ABOVE TOE	1	0	0	NA	NA	NA	NA	0	0
BETWEEN 2 & 3 PLY		0	0	NA	NA	NA	NA	0	0
TOTALS	10	0/10	2/10	1/5	6/7	4/6	3/7	0/10	0/10

TABLE 11

DETECTION OF 1/2 INCH DIAMETER SEPARATIONS

DEFECT LOCATION LOCATION IN SECTION LOCATION IN LAMINATE	INSPECTION METHOD NUMBER OF DEFECTS	VISUAL (OUTSIDE ONLY)	AIR NEEDLE (INSIDE)	AIR NEEDLE BUFF (OUTSIDE)	HOLO BFG	HOLO NRC	SONIC DOT	X-RAY BFG	X-RAY MONSANTO
CROWN	2	0	YES	0	YES	YES	0	0	0
BETWEEN 1 & 2 PLY		0	YES	0	APP	APP	0	0	0
CROWN	1	0	0	YES	YES	YES	0	0	0
BETWEEN TREAD & INSERTS		0	0	YES	APP	APP	0	0	0
SHOULDER	1	0	0	0	YES	0	YES	0	0
IN LINER SPLICE		0	0	0	APP	0	YES	0	0
SHOULDER	1	0	0	YES	YES	YES	YES	0	0
BETWEEN 9 & 10 PLY		0	0	APP	APP	APP	APP	0	0
SHOULDER	4	0	0	3/4	YES	YES	YES	0	1/4
BETWEEN 13 & 14 PLY		0	0	APP	APP	APP	APP	0	0
MID SIDEWALL	1	0	YES	0	YES	YES	NA	0	0
BETWEEN LINER & 1ST PLY		0	YES	0	APP	APP	NA	0	0
MID SIDEWALL	1	0	0	NA	NA	NA	YES	0	YES
BETWEEN 13 & 14 PLY		0	0	NA	NA	NA	YES	0	0
SIDEWALL AT ANNULAR RINGS	1	0	0	NA	NA	NA	YES	0	0
UNDER #2 FINISH STRIP		0	0	NA	NA	NA	APP	0	0
2" ABOVE BEAD	1	0	0	NA	NA	NA	NA	0	0
BETWEEN 8 & 9 PLY		0	0	NA	NA	NA	NA	0	0
TOTALS	13	0/13	3/13	5/9	10/10	9/10	8/11	0/13	2/13

TABLE 12

DETECTION OF ONE(1) INCH DIAMETER SEPARATIONS

DEFECT LOCATION LOCATION IN SECTION LOCATION IN LAMINATE	INSPECTION METHOD NUMBER OF DEFECTS	VISUAL (OUTSIDE ONLY)	AIR NEEDLE (INSIDE)	AIR NEEDLE BUFF (OUTSIDE)	HOLO BFG	HOLO NRC	SONIC DOT	X-RAY BFG	X-RAY MONSANTO
CROWN	1	0	YES	0	YES	YES	0	0	0
BETWEEN LINER & 1^{ST} PLY		0	YES	0	APP	APP	0	0	0
CROWN	1	0	0	0	YES	YES	YES	0	0
BETWEEN 13 & 14 PLY		0	0	0	APP	APP	YES	0	0
CROWN	1	0	0	YES	YES	YES	YES	0	0
BETWEEN TREAD & INSERTS		0	0	YES	APP	APP	YES	0	0
SHOULDER	1	0	YES	0	YES	YES	YES	0	0
BETWEEN 9 & 10 PLY		0	0	0	APP	APP	YES	0	0
SHOULDER	1	0	0	YES	YES	YES	0	0	YES
12 TO 14 PLIES		0	0	APP	APP	APP	0	0	0
MID SIDEWALL	1	0	YES	NA	YES	YES	YES	0	0
BETWEEN 1 & 2 PLY		0	APP	NA	APP	APP	YES	0	0
MID SIDEWALL	1	0	0	NA	NA	YES	YES	0	0
BETWEEN 12 & 13 PLY		0	0	NA	NA	APP	YES	0	0
SIDEWALL ANNULAR RINGS	1	0	0	NA	NA	NA	YES	0	0
UNDER #2 FINISH STRIP		0	0	NA	NA	NA	APP	0	0
BEAD STACK 2" ABOVE TOE	3	0	YES	NA	NA	NA	YES-1 NA-1	0	0
BETWEEN 2 & 3 PLY		0	APP	NA	NA	NA	YES-1 NA-1	0	0
BEAD STACK 2" ABOVE TOE	1	0	YES	NA	NA	NA	NA	0	0
BETWEEN 6 & 7 PLY		0	APP	NA	NA	NA	NA	0	0
TOTALS	12	0/12	7/12	2/5	6/6	7/7	7/9	0/12	1/12

If cost considerations permit two such inspections, probably they should be performed immediately after buffing and just before returning the retreaded tire to the warehouse or to service.

If only one advanced NDT inspection is affordable and the rejection percentage attributable to it is small, it should perhaps be done after retreading, before returning the tire to service to make sure no separations have developed in the retread process. If tires which had "acceptable size" separations could be recognized on a succeeding retread, these should be subject to an additional advanced NDT inspection after buffing since they would probably represent greater risks because of potential separation propagation.

If an "acceptable size" criterion for separations is adopted,the ultrasonic system would be at some disadvantage, since it seems to be less discreet in size determination than, for instance, the holographic system.

The primary increased capability offered by the advanced NDT system is improved detection and size determination of separations.

Little published information was located to suggest separation size criteria or to offer statistical support for such criteria. Also very little published statistical support was found to indicate the probable rejection rate of candidate aircraft tires attributable to implementation of advanced NDT inspection methods or to indicate what improvement in tire service could be expected.

The best public source of information on advanced NDT inspection criteria and effectiveness was in the published, and yet to be published, "Proceedings of Symposia on Nondestructive Testing of Tires" sponsored by Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172 and distributed by National Technical Information Service(NTIS), U.S. Department of Commerce, Springfield, Virginia 22161.

3.10 CONCLUSIONS

3.10.1 GENERAL

There are several general conclusions which can be drawn from this evaluation study. These are briefly outlined here followed by conclusions that pertain to the specific inspection systems evaluated.

- Air carrier aircraft tires exhibit wide variation in the number of retreads that can be safely sustained and the number of take-off/landing cycles sustained between successive retreads.
- There is no single NDT inspection system that can detect all potentially unsafe tire defects.
- None of the advanced NDT inspection systems evaluated will eliminate the need for direct visual tire surface inspection and/or the air needle inspection method.
- The primary additional inspection capability provided by the advanced NDT inspection systems over the air needle method is the improved detection and size determination of unbonds or separations between tire carcass plies.
- Separations can be indication of deterioration of carcass structural integrity.
- Separations tend to grow in size or propagate with continued tire service. The propagation rate is subject to variation caused by service conditions and tire construction.
- Disqualifying tires because of carcass separations detected by advanced NDT inspection methods has reduced tire removals from aircraft for reasons other than tread wear for some air carriers.
- A widely practiced acceptance criterion for separation size appears to be: No separation dimension greater than 1/4 inch is acceptable in a tire shoulder or sidewall and no dimension greater than 1 inch in a crown separation. There is no extensive statistical evidence to support this dimensional criterion.
- There is a need for the accumulation of statistical evidence to improve acceptance criteria confidence.
- The effectiveness of any inspection method is dependent on the knowledge, skill, and diligence of the inspector.

3.10.2 CONCLUSIONS - DIRECT VISUAL INSPECTION

- Direct visual inspection is necessary for the detection of some surface defects not detectable by other methods; for instance: ozone deterioration of surface, overheat deterioration, surface cuts and abrasions.

3.10.3 CONCLUSIONS - AIR NEEDLE METHOD

- Air needle inspection should include careful direct visual and tactile inspection of the complete liner surface, and of bead flat and heel, and, after retreading, vent hole function.
- This is the only method which detects liner leaks.
- This is the only method that verified vent hole function.
- This method does not detect some separations as large as one(1) inch diameter between inner carcass plies.
- The exact location of a separation within the laminate can sometimes only be approximately determined.

3.10.4 CONCLUSIONS - AIR NEEDLE BUFFING

- This method includes the buffing away of the relatively thick tread and shoulder rubber that would normally be removed in the retreading process and it provides inspection capability only in or near that buffed area.
- Separations adjacent to or outside of the undertread reinforcing plies are eliminated in the buffing process and do not confuse the acceptance/rejection decision.
- This method is not effective in locating small separations in the inner or mid-carcass area.
- An air injection soak time of 15 to 20 minutes prior to mounting on the buffing machine could improve the effectiveness of this inspection as compared to the method used in this evaluation.
- The cost of the buffing equipment modification necessary to implement this method is very low.
- The buffing machine operator must have only minimum tire inspection skills.

3.10.5 CONCLUSIONS - HOLOGRAPHIC METHOD

- In this evaluation, this was the most effective method for detecting separations and indicating their size.
- This method can provide an approximate indication of the location of the separation in the carcass laminate, but only after some time consuming study, comparison, and analysis of the hologram.
- Equipment for this test method is commercially available.
- Tires must be spread and normalized before crown and shoulder inspection by this method.
- One side of a bead and one sidewall can be inspected by additional manipulation and inspection; likewise for the other bead and sidewall.
- This method also gives indication of carcass degradation, poor adhesion,"weak" splices, undercure, flex break, and liner porosity.
- Inspection machine adjustments must be made to accommodate different tire sizes.
- A maximum inspection rate of approximately 10 tires per hour is the present capability with a 2 or 3 man crew, the crew size depending on equipment type. Bead-to-bead inspection would be significantly slower.

3.10.6 CONCLUSIONS - ULTRASONIC METHOD

- This method is possibly as effective as the holographic method for detecting separations,except over bead wire.
- This method provides the best indication of location of defects in the tire laminate.
- This method was not able to discriminate the size of a separation or anomaly as well as the holographic method.
- This method detects too much. It is difficult to discriminate critical anomalies from non-critical anomalies and electronic "noise".
- The transducer locations must be changed with precision for each change in tire profile and size;or a separate transducer and yoke assembly must be provided and changed for each tire size.
- There is no off-the-shelf commercial design available for aircraft tires.
- The visual display does not resemble a tire and is more difficult to relate to a tire construction.

- This method could enable a complete bead-to-bead scan of a tire during a single test machine cycle.
- The test data display is complex and requires more analysis time than for other test methods.

3.10.7 CONCLUSIONS - X-RAY METHOD

- Except for visual surface inspection, this method was the most ineffective for detecting separations.
- This method was ineffective for indicating the location of an anomaly in the ply lamination.
- This was the only method which indicated bead wire position, unless there was a wild wire near a surface which produced a surface protrusion.
- Where there are three bead bundles, as in the test tires, the center bundle is shielded from x-ray viewing by the inner and outer bundles.
- This method can indicate folded turnups or chafers.
- This method can indicate open ply splices.
- X-ray inspection equipment for aircraft tires is commercially available and widely used for examining tire construction(but not for qualifying aircraft tires for retread).

4.0 REFERENCES

1. Grant, R.M., "Evaluation of the Structural Integrity of Pneumatic Tires by Holographic Interferometry","Proceedings of the 1973 Symposium on Nondestructive Testing of Tires", edited by Paul E. J. Vogel, Materials Manufacturing and Testing Technology Division, Army Materials and Mechanics Research Center, Watertown, Mass., held at the Parker House, Boston, Mass., 10-12 April 1973, pages 33-46.
2. Grant, R. M., "Comments Upon the StructuralIntegrity of Truck Tires as Observed by Holography", published in "Proceedings of the Second Symposium on Nondestructive Testing of Tires", edited by Paul E. J. Vogel, Materials Manufacturing & Testing Technology Division, Army Materials and Mechanics Research Center, distributed by National Technical Information Service(NTIS), U.S. Department of Commerce, Springfield, Virginia 22161.
3. Shaver, W.C., "Holography as Applied to Aircraft Tires", published in "Proceedings of the Second Symposium on Nondestructive Testing of Tires", edited by Paul E. J. Vogel, Materials Manufacturing & Testing Technology Division, Army Materials and Mechanics Research Center, distributed by National Technical Information Service(NTIS), U.S. Department of Commerce, Springfield, Virginia 22161.
4. Zimmerman, T. R., "Comments Upon the Past, Present and Future of Holographic NDT of Pneumatic Tires", presented at and yet to be published in the "Proceedings of the Fourth Symposium on NonDestructive Testing of Tires", held at Buffalo, New York in May 1978. Available from Industrial Holographics,Inc., Auburn Heights, Michigan 48057.
5. Grant, R. M., "Failure Analysis of Aircraft Tires as Observed by Holography", presented at and yet to be published in the"Proceedings of the Fourth Symposium on NonDestructive Testing of Tires", held at Buffalo, New York in May 1978. Available from Industrial Holographics,Inc., Auburn Heights, Michigan 48057.
6. Ryan, R. P., "Feasibility of High-Resolution Pulse-Echo Techniques for Automobile Tire Inspection", June 1973, Report No. DOT-TSC-NHSTA-72-11, prepared for Department of Transportation, National Highway Traffic Safety Administration, Research Institute, Washington, D.C. 20591, distributed by National Technical Information Service(NTIS),Springfield,Virginia 22161.

4.0 REFERENCES (Continued)

7. Ryan, R. P.,"A Semi-Automated Pulse-Echo Ultrasonic System for Inspecting Tires", July 1977, Report No. DOT-TSC-NHTSA-76-3, prepared for U. S. Department of Transportation, National Highway Traffic Safety Administration, Office of Research and Development, Washington, D.C. 20590, distributed by National Technical Information Service(NTIS), Springfield, Virginia 22161.

APPENDIX A

APPLICATION OF ULTRASONIC PULSE-ECHO TECHNIQUES TO NONDESTRUCTIVE INSPECTION OF AIRCRAFT TIRES

Development Status

Teknekron has developed a three station, 24 channel ultrasonic pulse-echo tire inspection system for automobile tires for the U.S. Department of Transportation, Transportation Systems Center in Cambridge, Massachusetts. The inspection technique is regarded by DOT as having the highest potential for an assembly line NDT system. The system is currently being used by DOT in its research of tire defect classification. Teknekron has been actively supporting DOT in its tire research since the installation of the system in March 1975.

The enclosed brochure describes the system in detail. The electronic subsystem is flexible and can be configured to scan airplane tires with ease. Smaller tire sizes can be accommodated without any change in the mechanical handler. To provide better penetration into the thicker tires, 1 MH2 transducers can be used instead of the 2.25 MH2 units.

Applicability of System to Service all Sizes

The electronic subsystem can be set up to accommodate all tire sizes by simply selecting a different switch position or typing the appropriate command on a computer terminal.

When tire sizes are changed, another transducer mount for the new tire size can be installed. Each tire size can have a different transducer mount for repeatable, quick servicing of tire size changes.

The mechanical system can be designed to handle different rim widths and diameters to cover the entire range of aircraft tires.

When a mix of tires must be inspected the optimum configuration would be to have switchable transducer arrays for each size. The NDT system then switches to the proper transducer bank and rim size on command from the operator. The implementation can be a manually operated or total automatic system.

Capabilities for Equipment Check Out, Calibration and Troubleshooting

Built in diagnostic hardware and software can be incorporated in the electronic subsystem. To check system scanning, a test tire can be scanned and results compared to the known condition of the tire.

Redundancy Features

Redundant circuits can be incorporated in areas where single point failures jeopardize operator safety. This inherent low energy inspection technique requires no special protection for the operator.

Repair Service

Teknekron supports users of its NDT systems and provide maintenance service under service contracts.

Operator Skills and Training

The usual mechanical skills of operating control panels and tire handling equipment are sufficient. The training period for the use of the NDT equipment is estimated to be 2-4 weeks.

Utilities

Standard utilities such as 115 and 230 volt single phase wiring, water supply and adequate drainage, and 100 psi air are required.

Environmental Protection

No special precautions are required for environmental protection.

Operator Protections

High voltage areas are properly shielded and guards are placed over exposed gears and potential mechanical hazards.

Inspection and Analysis Time

Total inspection time which constitutes mounting tire, scanning, and dismounting requires one to two minutes per tire. Data is available immediately and can be visually analyzed in less than five minutes. On line computer storage and analysis can reduce this time. It is desirable to incorporate some kind of archival storage and retrieval system for statistical analyses.

Purchase, Operating, Maintenance Costs

Estimated development cost for a 32 channel tire inspection system capable of handling the range of aircraft tires one at a time with data display for manual analysis is $200,000. The cost of subsequent systems is estimated to be in the $100,000 range. Installation cost is estimated to be $15,000.

Operating costs due to utilities are nominal. Other operating costs are labor costs for two operators and depreciation over a five year life.

Maintenance costs are approximately $12,000 annually which covers a service contract.

Operator training consists of one man month of labor per operator.

Maintenance training should require one man month of labor per worker.

Seriousness of Tire Defects

At this point in the state of the art, the pulse echo inspection technique clearly detects tire flaws and features such as separations, splices, tire thickness, and wandering belts. However, without road testing of anomalous tires to correlate defects with failures no reliable information regarding the useful service life of a tire can be made. Tires with large separations obviously will be rejected, but there is evidence that certain separations clearly identified by the NDT system never "grow" or lead to tire failure.

APPENDIX B

NON-DESTRUCTIVE TESTING OF AIRCRAFT TIRES

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Transportation Systems Center
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PROJECT MEMORANDUM

OCTOBER 1978

Prepared for

U.S. Department of Transportation
Research and Special Programs Administration
Washington DC 20590

GLOSSARY

<u>Anomaly:</u> Departure from a regular condition. Specifically, in Ultrasonic Nondestructive inspection a deviation from the regular pattern of ultrasonic traces appearing in the hard copy trace of the ultrasonic tire inspection system.

<u>Analysis:</u> The act of inspecting the ultrasonic hard copy printout, listing the location and severity of any anomalies as a function of their probable impact on five discrete parts of the tire: tread, belt, sidewall, carcass, liner.

<u>Defect</u>: A latent condition within a failed tire found by nondestructive inspection or failure analysis as the cause of a specific failure.

<u>Failure</u>: A tire which has been considered to have failed MVSS 109. Specifically, one having any of the defects called out in that regulation; cord separation, groove or liner cracks, loss of air. A tire can be considered a failure even if it was not identified as such if the above defects can be proved to exist by nondestructive means.

<u>Failure Analysis:</u> The act of sectioning and inspection of a tire to attempt to understand what condition led to failure of the tire.

<u>Failure Mechanism</u>: The detection and logical connection between a condition judged to exist within a tire prior to its failure and the subsequent failure of that tire.

<u>Flaw</u>: A characteristic within a tire which could be expected to lead to its degradation and possible failure.

<u>Singularities</u>: An anomalous condition observed within the tire either during visual inspection or during sectioning and analysis. It is a condition in which there is no known link to degradation and failure.

INTRODUCTION

Early in 1978, in response to the need for improving the reliability of aircraft tires in service, the Federal Aviation Administration initiated a program aimed at assessing the relative merits of the available nondestructive inspection techniques for inspection of aircraft tires*. An important resource for nondestructive tire inspection was already available in DOT at the Transportation Systems Center where over the past six years the National Highway Traffic Safety Administration had been developing nondestructive techniques specifically for tire inspection The obvious commonalities in the requirements of the two programs led the FAA to solicit the assistance of NHTSA in evaluating nondestructive inspection for aircraft tires. The FAA awarded a contract to B.F. Goodrich to provide aircraft tires having "classical" anomalies, defects, and singularities and also to evaluate the available nondestructive inspection techniques in terms of the needs of the aircraft industry. TSC was directed by NHTSA to provide consultation on the available technology and also to perform inspection services subject to the availability of equipment and personnel.

The contractor selected eight aircraft tires having a variety of defects as being representative of most of the dangerous conditions encountered in aircraft tires. These were shipped to a number of laboratories having nondestructive inspection capabilities. The tires were ultrasonically inspected at TSC and this report is a description of the work accomplished and the results obtained.

*On September 6, 1978 the National Transportation Safety Board issued a priority recommendation which states in part, as follows: "expedite the development of a nondestructive technique which would detect flaws in tire carcasses --- require nondestructive inspection for new and retreaded tires and develon criteria based on such inspection to withdraw a faultv tire from service."

Specifically ultrasonic nondestructive inspection located 92% of the known anomalies and a large number of anomolies which were not known. Conclusions from these findings are that ultrasonics is ready for an important role in nondestructive aircraft tire inspection, and only awaits engineering development of suitable equipment dedicated to the specific needs of the industry.

2. SYSTEM DESCRIPTION

2.1 General

In tire inspection by reflection ultrasound, first demonstrated at TSC in 1975, narrow-band pulses of ultrasonic energy are coupled acoustically to a tire by a water envelope. This energy penetrates the tire and sends return reflections from lamina within the tire. The system in use at TSC is equipped with twenty-two transducers to obtain coverage of the complete tire, although only fifteen were used in this study.

The tire-handling part of the tire-inspection machine is shown in Figure 1. This tire handler is an immersion system with a large tank 4 feet deep.

The tire is mounted and inflated on the vertical rim of a three-arm spider. This rim and spider is then moved 120° down into the water where the tire is rotated. Then high pressure water jets remove bubbles and debris. Meanwhile a second tire may be mounted on the spider arm which has moved into the vertical mounting position. After debubbling, the spider is again rotated and the tire is now under water at the inspection position where it is surrounded by an array of transducers as shown in Figure 2. This picture shows the transducers and tire in their proper orientation raised out of the water for clarity.

The inspection scan requires about 20 seconds, after which the spider is rotated 120° to the vertical position. The tire is deflated, removed, and replaced with another and the entire cycle repeated.

Faster processing is possible but difficult to achieve because of water turbulence in the tank. Because of their size, and the fact that the equipment was not designed for them, aircraft tires require a processing time on the order of eight minutes per tire.

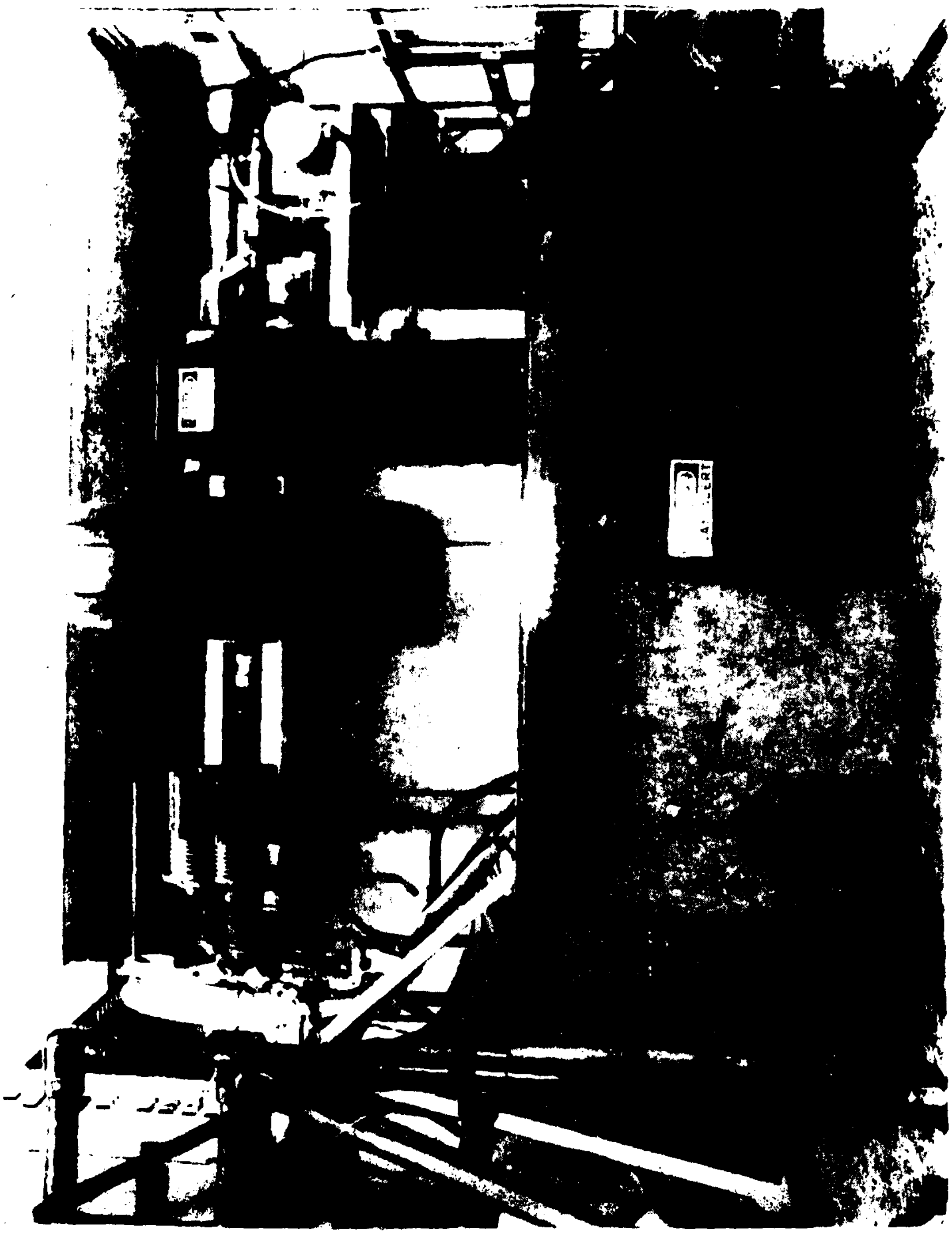


FIGURE 1

FIGURE 2

2.2 SETUP OF TRANSDUCERS

Reflection ultrasound inspection requires utrasonic energy flux, from and to the transducers, perpendicular to the laminar structure within the tire. To facilitate this, each transducer is independently adjustable. This adjustment must be carried out manually underwater. Setup for a group of similar tires requires about a half hour. No adjustment is necessary for a sequence of similar tires of the same manufacture.

Figure 3 is a sketch of the cross section of a typical aircraft tire with transducers arrayed around it as they were for this study. Lack of tank space for the larger aircraft tires permitted setup of transducers only on the tread and one side of the tire so that any anomalies which appear exclusively on the side opposite the serial number were not detected. It would have been possible to rotate the tire and obtain data on the side opposite the serial, however, it was felt that the capabilities of the system would be conclusively demonstrated without this time consuming step. Any setup for production inspection of aircraft tires would employ a full battery of transducers around the tire.

2.3 AIRCRAFT TIRE DISPLAY

Figure 4 is a presentation of the display of a complete aircraft tire which has been scanned by ultrasound. There are fifteen channels of ultrasonic inspection data starting with channel 2 at the left of the display and ending with channel 16 at the far right. The 0° rotational position of the tire is at the top of the image and the tire is scanned clockwise when looking at the serial side. Ninety degrees is one quarter of the way down the display, 180° is halfway, etc. Channels 2 and 3 are on the serial number side sidewall. The balance of the channels are in a region of the tire where at least some tread exists. The bright white line to the right of each channel represents the liner. The point labeled "A" is a separation in the tire at about the thirteenth ply. Notice the shadow region where the high level of reflection at the separation has prevented penetration (and

TRANSDUCER CONFIGURATION
(AIRCRAFT TIRES R-8118)

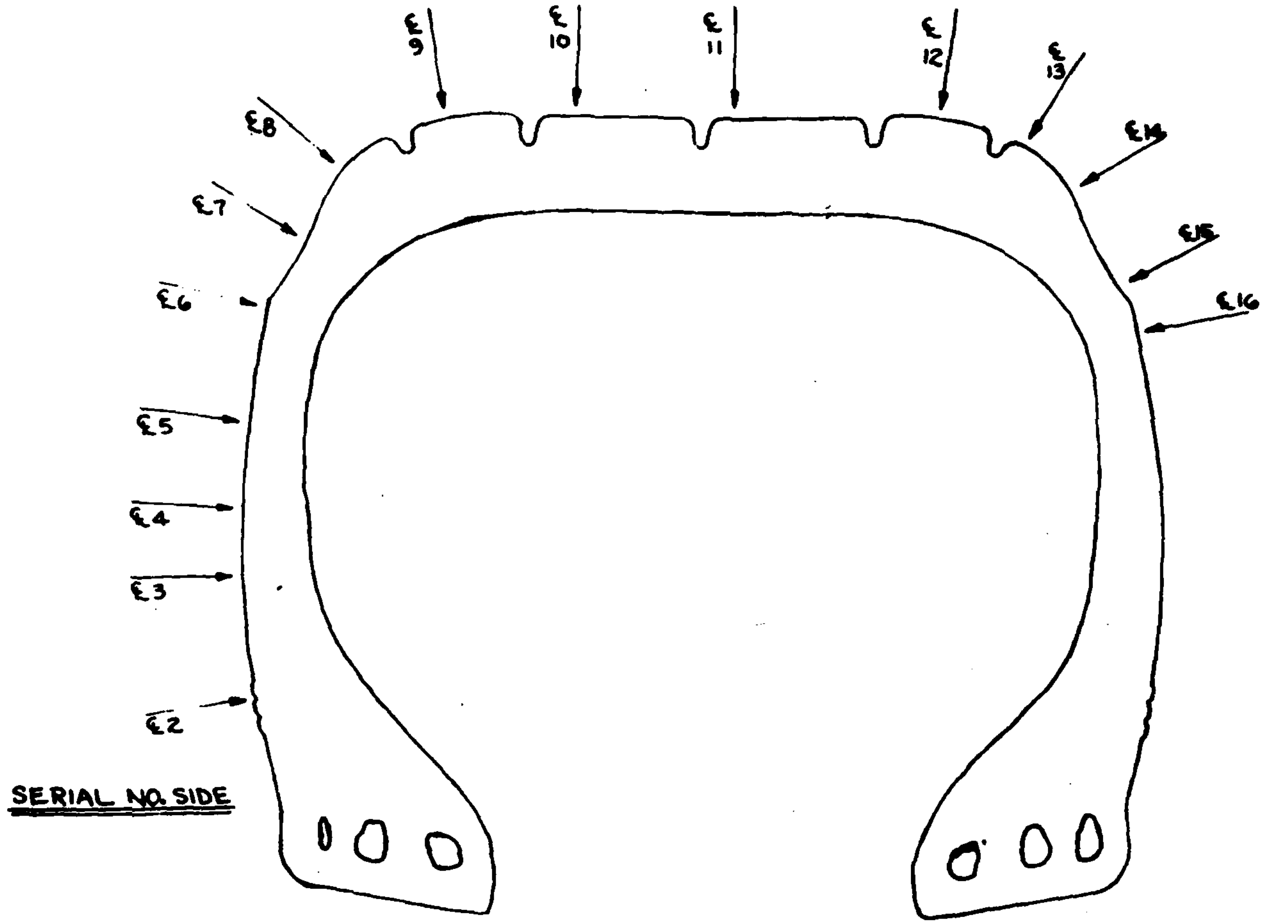
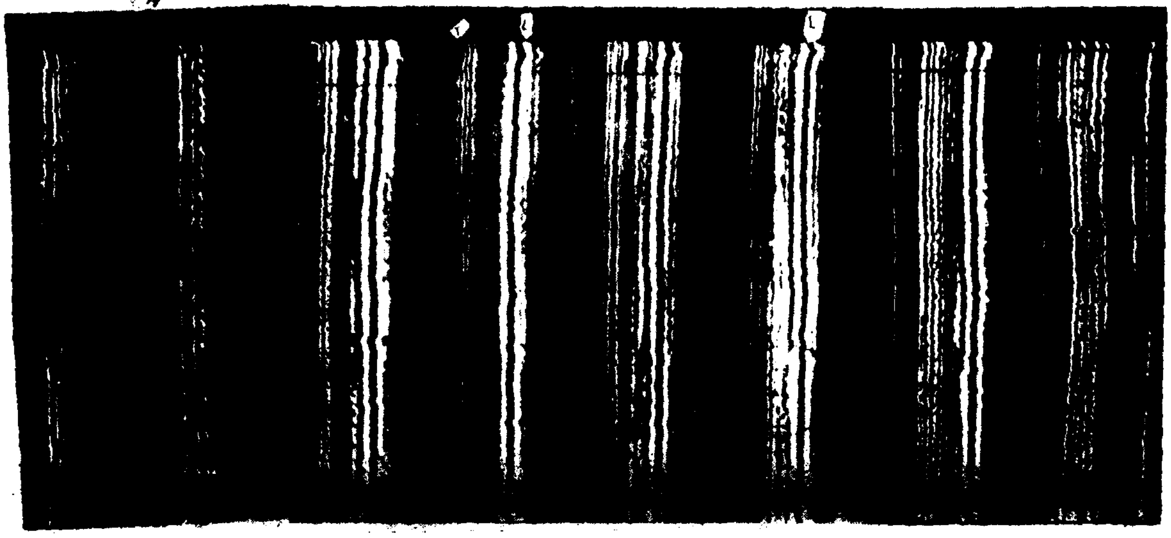


FIGURE 3



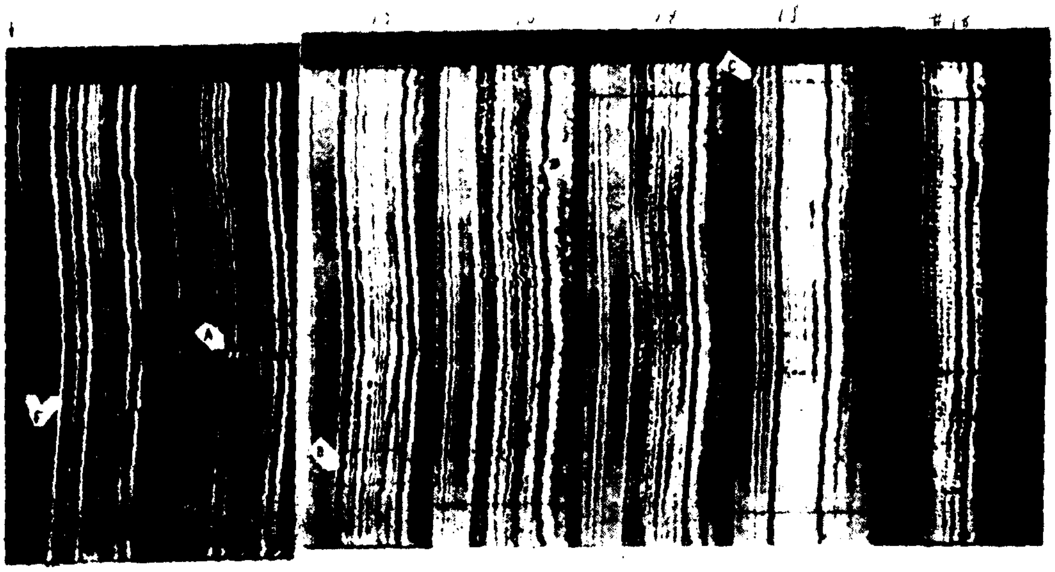


FIGURE 4

therefore reflection) of energy deep into the tire. "B" is a much smaller separation creating a similar disturbance at inner ply layers. "C" represents a shadow in the ply structure created by placing a band around the tire at the 0° location. This condition is also easily observed in Channels 12 thru 16, and to a lesser extent in all other channels. "D" and "E" are both anomalous conditions in the liner. In the case of "E", the condition appears over two inches in the shoulder. In the case of "D" the extent of the anomaly is much smaller. The twin arrow at "F" indicates the location of the tread surface and the outer ply layer, respectively. The multiple arrows at the center of channels 7 through 14 represent a disturbance caused by an irregular splice system. The eccentricity of this tire should be noted. Channel 11 is situated at about tread center. This trace undulates sinusoidally along its vertical axis and from it the measured runout of this trace is 1/8" at tread surface. Tire thickness at tread center is about one inch. Other singularities exists within this image. These will be discussed as a part of the comparison of the data concerning flaws known to be in this tire in a later section.

3. DESCRIPTION OF THE STUDY

Eight 34" x 11" x 22 ply tires were provided for the study. These contained a variety of defects. Some of these defects were introduced into the tires during operational use and some were introduced artifically during building and retreading. The object of the work at TSC was to compare the results of ultrasonic nondestructive inspection and analysis with the results from other insepction and test techniques. Each tire was inspected using the ultrasonic tire inspection system, the data analyzed, and the results compared with flaw data from other tests submitted with the tires. There was no assurance that the data from the other methods contained all of the flaws or anomalies within these tires. The following sections contain the findings of both the ultrasonic inspection and the data from other inspections. They are compared and the results tabulated.

4. ANALYSIS AND COMPARISON OF DATA; GENERAL

The following section describes the findings of the ultrasonic inspection and compares them to the information submitted with each tire. In many cases the results of the analysis of ultrasonic data are tentative since there is not the large backlog of experience with aircraft tires as is the case with passenger car tires. For example, the separations found in these tires appear to be very well defined. It is not clear whether this is because they occur in this manner in aircraft tires or whether these flaws have been intentionally introduced.

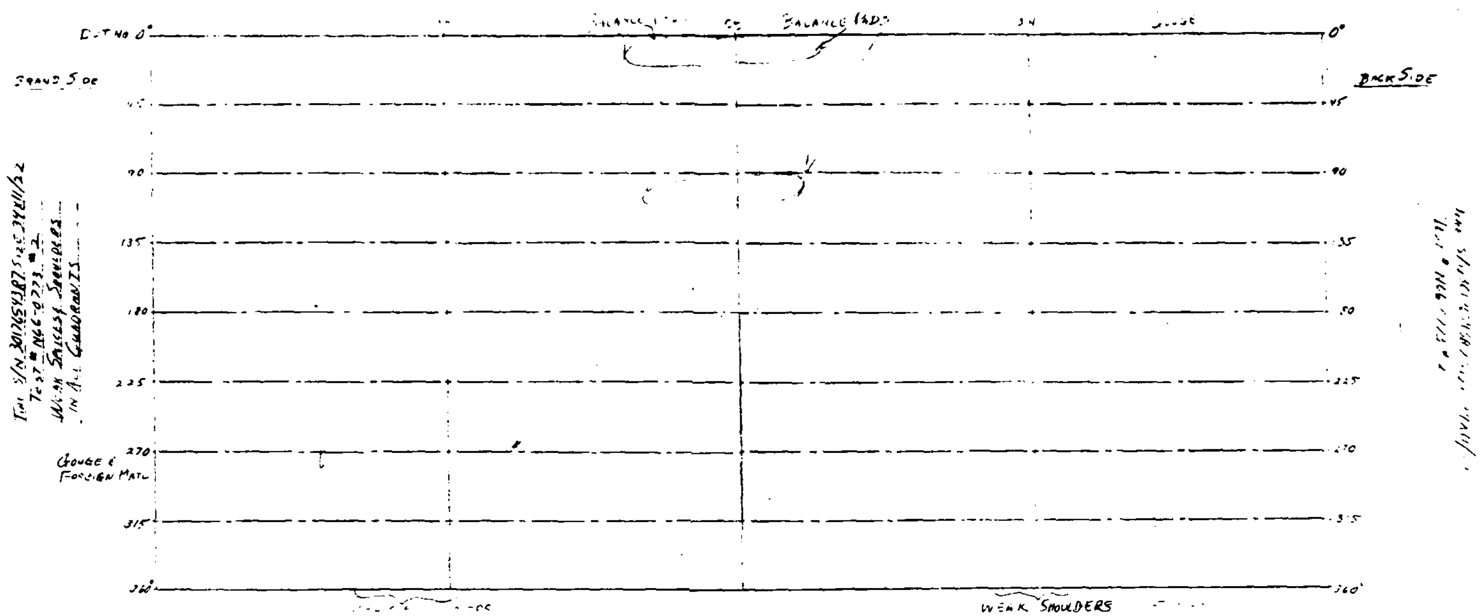
Naturally produced separations, at least in passenger tires, tend to be more irregular and bunched depending on the cause for their occurrence. Also, coverage of the tire by ultrasound was incomplete because transducers were concentrated on one sidewall and shoulder. Consequently, the sidewall opposite the serial number was not covered, there was also a gap between transducers No. 10 and 11, and a gap between 11 and 12. These gaps can account for most of the discrepancies between the ultrasonic findings and the flaw data submitted with the tire.

N 66 0773 #2 - The information submitted with the tires is inconclusive. On the other hand, ultrasound yielded a considerable amount of information. Channel 9 shows evidence of massive extra tread thickness at about 170° rotation from 0°. Channel 10 shows a possible separation and channel 11 shows, in addition to the balance pads, an open splice and evidence of a very thin tread section about 180° away from the balance pads.

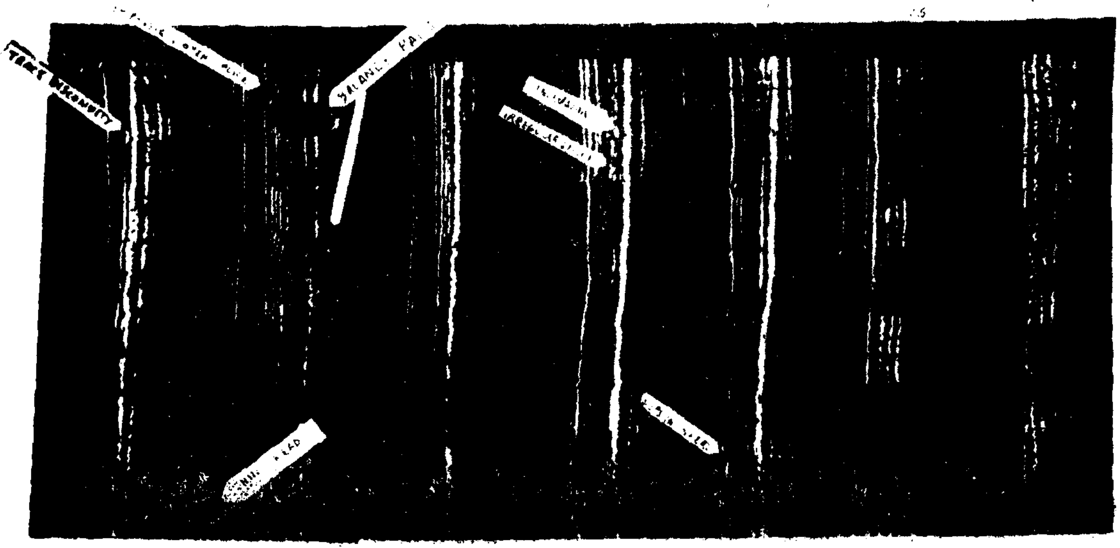
N 66 0773 #3 - Ultrasound detected five of six anomalies described in the information submitted with the tire.

In addition several anomalous areas were identified near the tread inserts, a very small puncture was identified in channel 7 and worn-through tread inserts were observed.

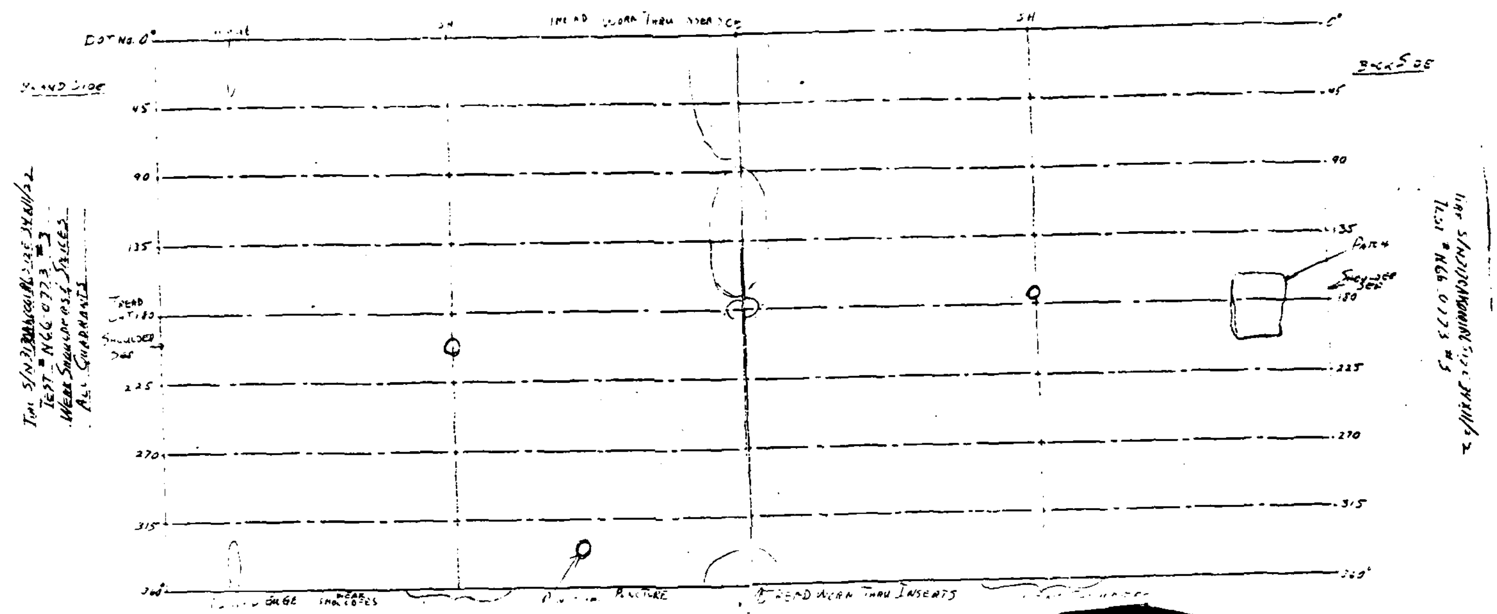
N 66 0773 #4 - The information submitted with this tire shows weak shoulders and two singularities. There may be a relationship


0°
BACK SIDE
45
90
135
180
225
270
315
360°
BALANCE PADS
GOUGE & FOREIGN MATL
WEAR SHOULDERS
Test # N66-0773 #2
Wear Shoulders
in All Quadrants

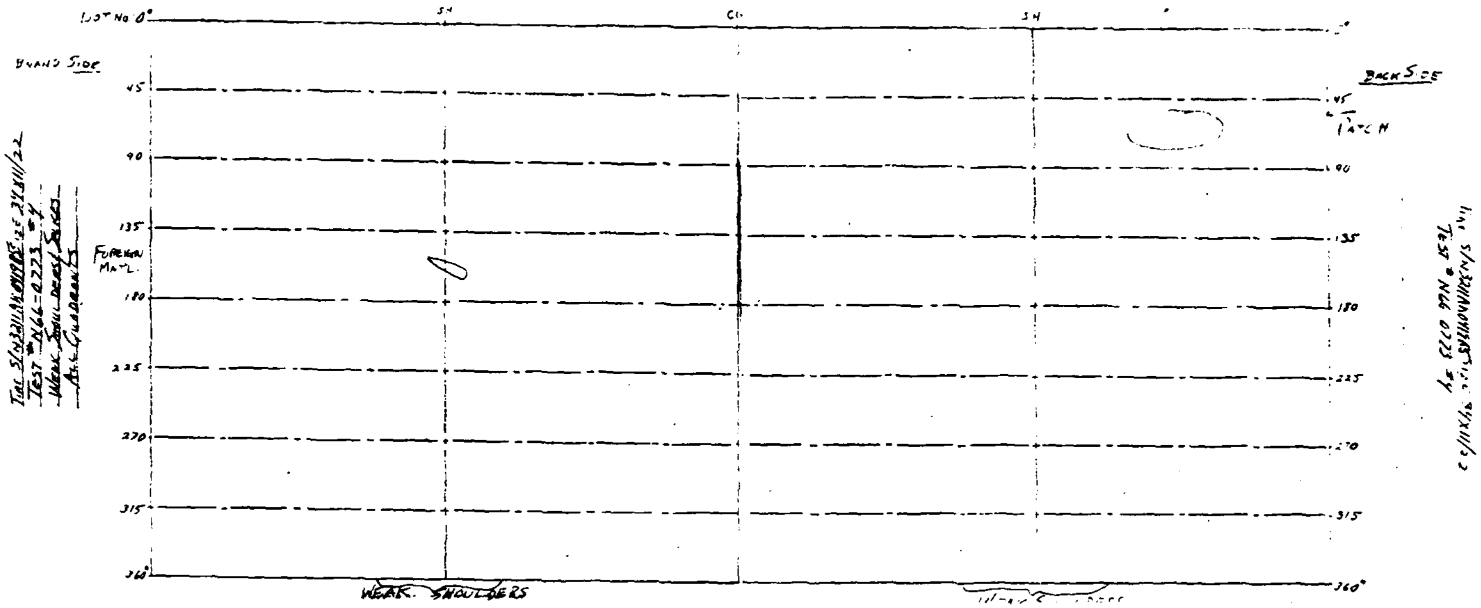
N66-0773 #2



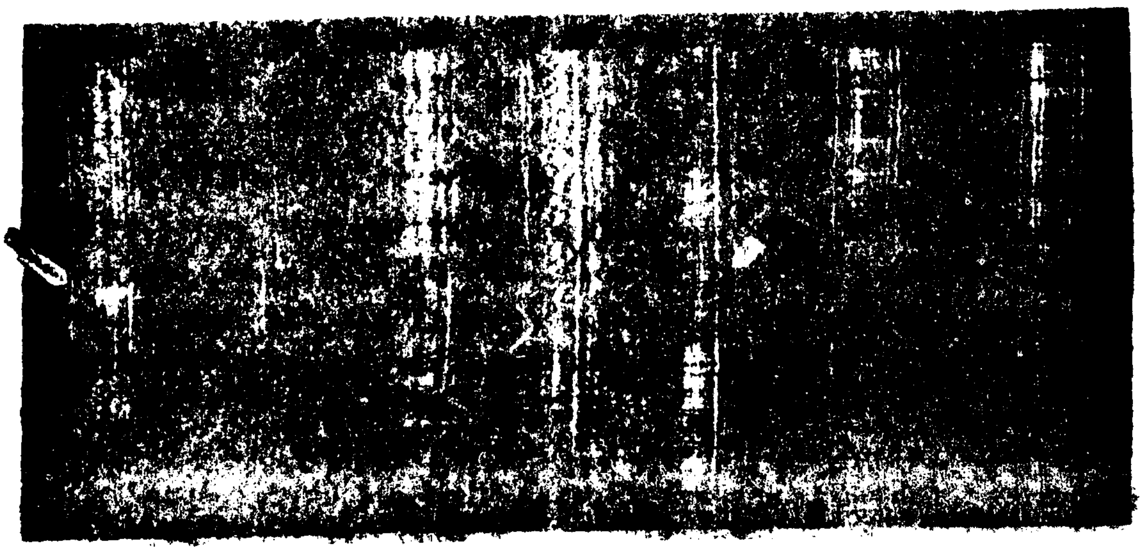
N66-0773 #2


DOT No. 0°
BACK SIDE
SH
SH
45
90
135
180
225
270
315
360°
TREAD WORN THRU INSERTS
PATCH

N66-0773 #3


BRAND SIDE
BACK SIDE
0°
SH
CL
SH
45
90
135
180
225
270
315
360°
PATCH
FOREIGN MAT'L
WEAK SHOULDERS
TEST # N66-0773 #4
WEAK SHOULDERS
ALL QUADRANTS
TEST # N66 0773 #4

N66-0773 #4



N66-0773 #4

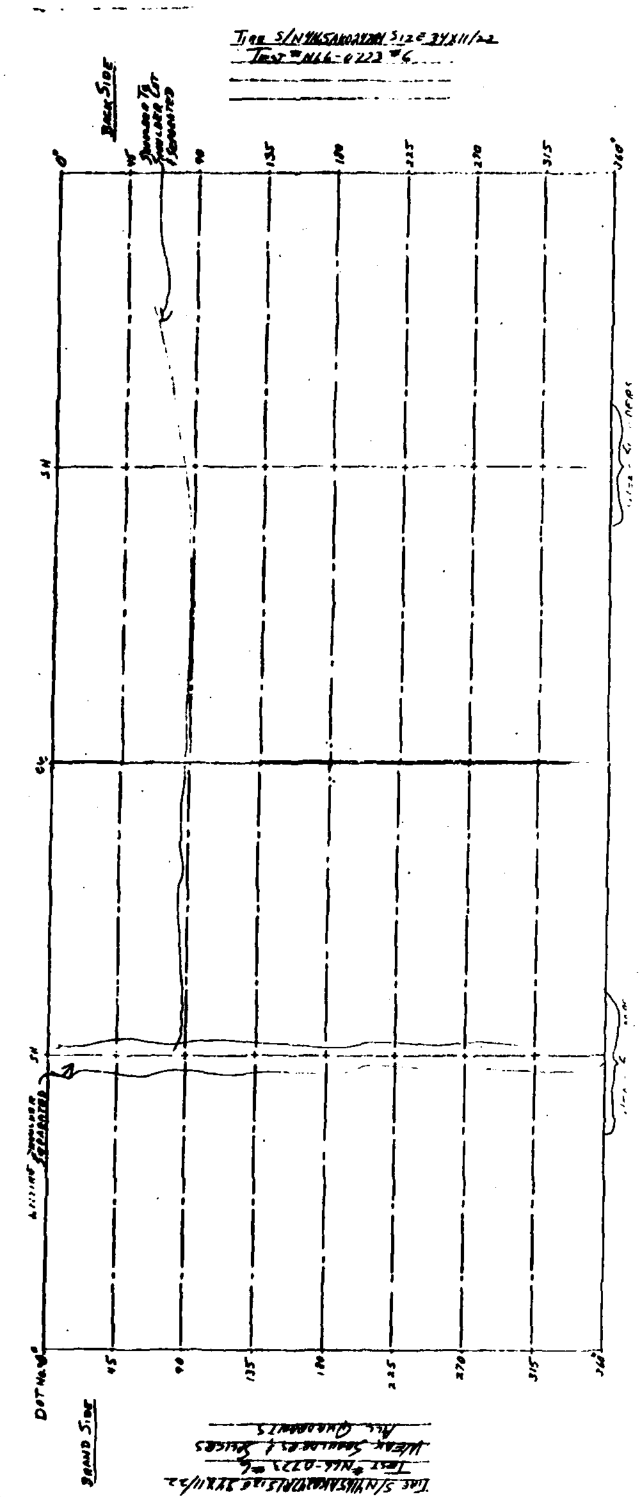
between the seps seen by ultrasound and the weak shoulders as described in the received information. If this is the case the two sources of data correlate well in this tire.

The singularity noted in Channel 10 is undoubtedly one of the buzzouts done in an attempt to secure adhesion around a cut. No attempt was made to orient the system to detect these.Channels 5, 6, and 7 appear to have anomalous conditions within the outer ply layers. In some cases deeper plies have been obliterated leading to the assumption that these are separations.

N 88 0773 #6 - Two singularities were noted on the information sheet submitted with this tire: a continuous separation along the serial number side shoulder and a separated cut within the tire. These two singularities were noted with reservations. First, to the ultrasound, the separations along the serial shoulder were intermittent, there being four principal major separations and a series of minor ones. The cut shown in the flaw data shows at the top of the ultrasonic image, however, this sometimes appears on the surface and sometimes at the ply layer. It is difficult to interpret this data. Since the visual inspection only noted surface cuts which were also detected by ultrasound, it may be assumed that the major cut was under the surface.

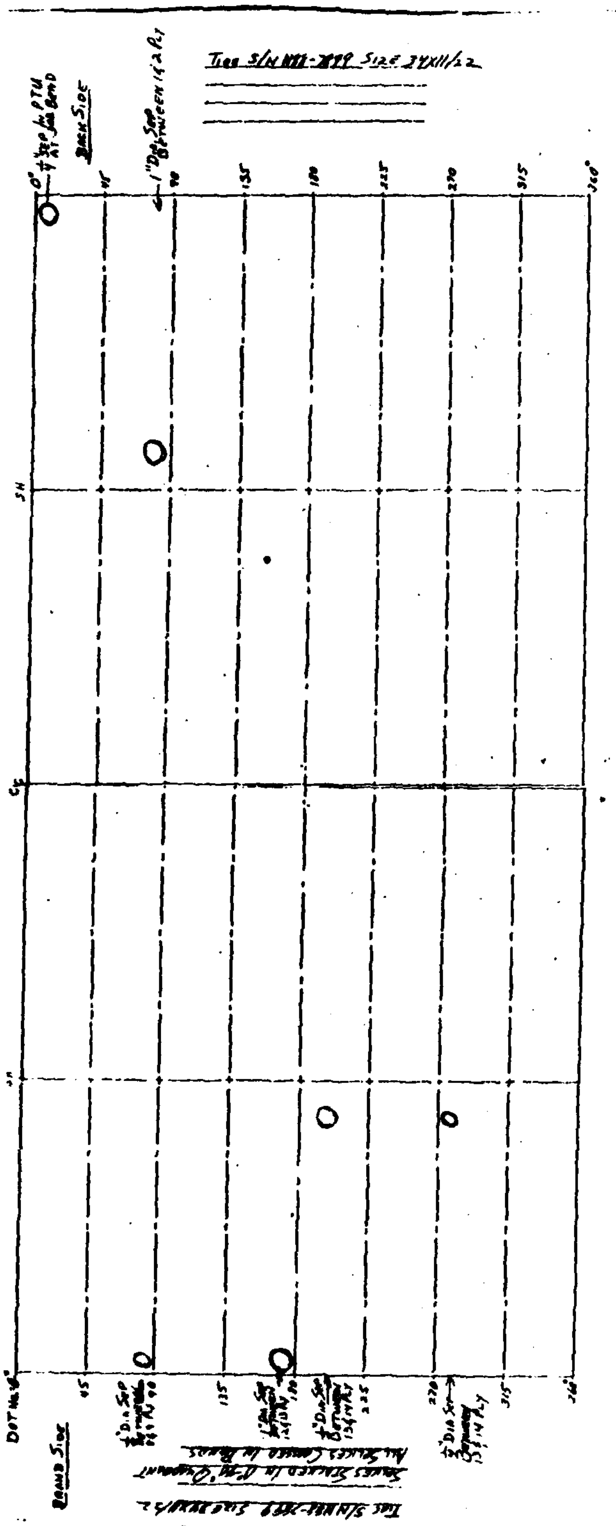
N 88 7899 - Information submitted with the tire cites 6 separations where ultrasound found only 4. The other separations were probably out of the viewing field of the sensors used on this tire. In addition to the separations, ultrasound identified heavy tread inserts and liner splices. The separations on the serial number sides of this tire appear to be natural separations, that is, not artificially induced unless done by the air needle. The separations appear best in channels 5 and 6 and show up as distortions of the liner signals. The separation in channel 15 is nearly masked by the existence of a heavy liner splice.

N 88 7900 - The information submitted with the tire, lists the following:8 separations,3 open splices. Ultrasound detected all eight possible separations, anomalous conditions in at least

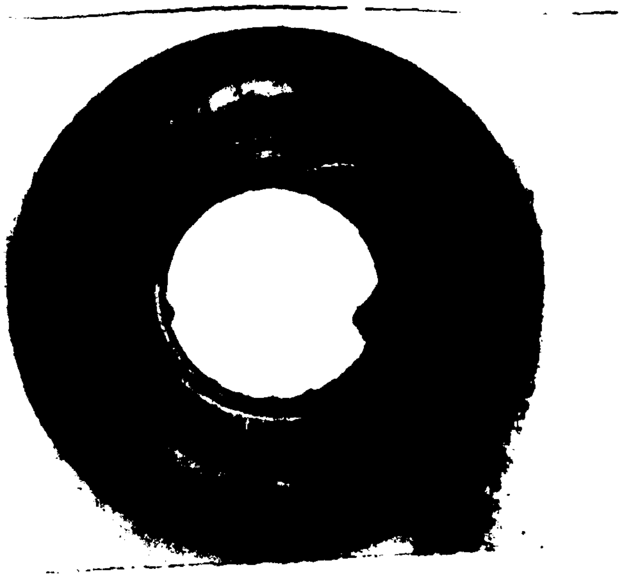


N88-0773 #6

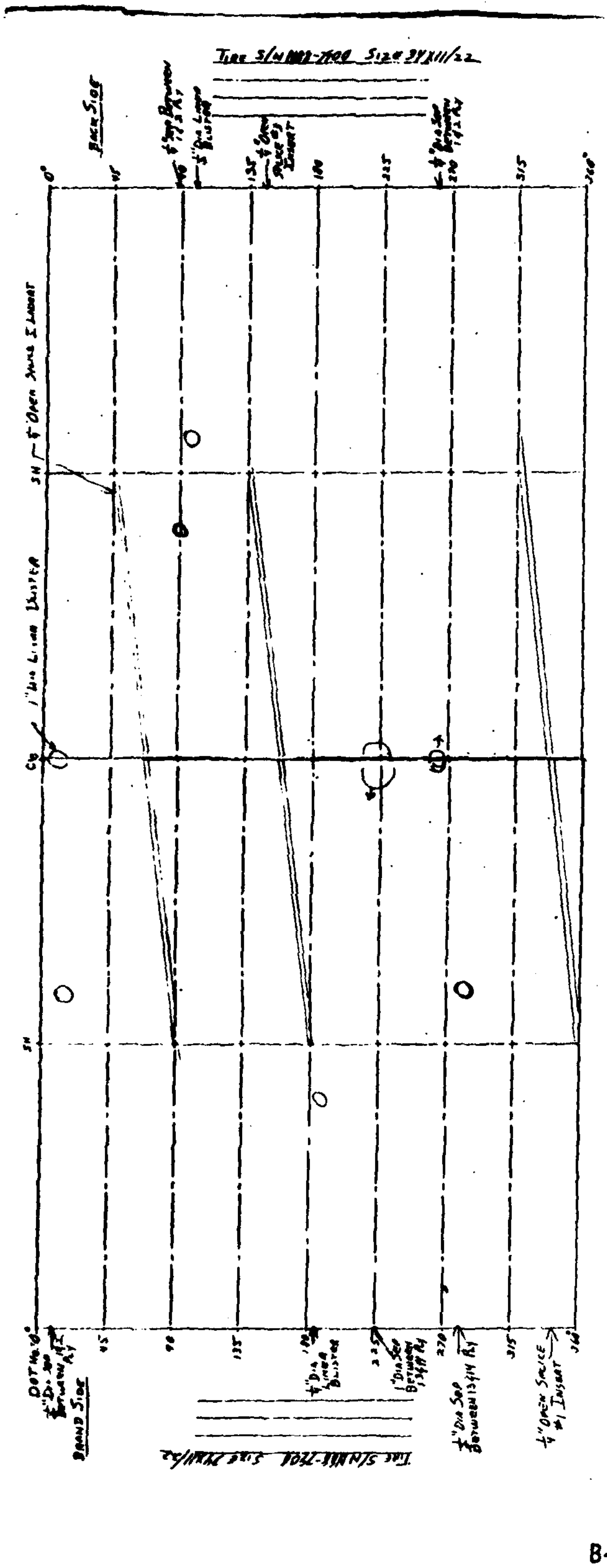
N88-0773 #6


Brand Side
Back Side
1" Dia. Sep Between 1 & 2 Ply
45
90
135
180
225
270
315
360°

N88-7899



N88-7899



N88-7900

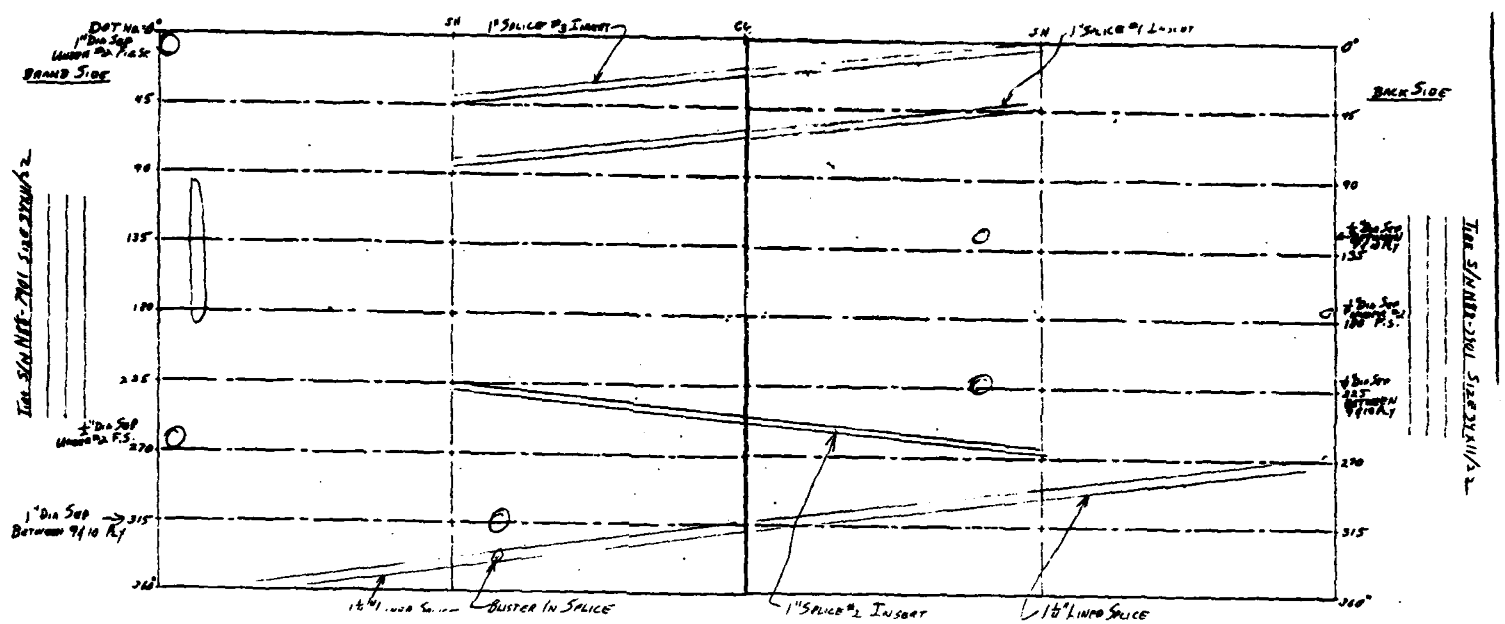
N88-7900

part of the liner, and several conditions not listed in the existing flaw data. An anomaly is noted in channel 9. This actually extends to channel 10, and 11 and could be either a separation or an anomaly in the splice.

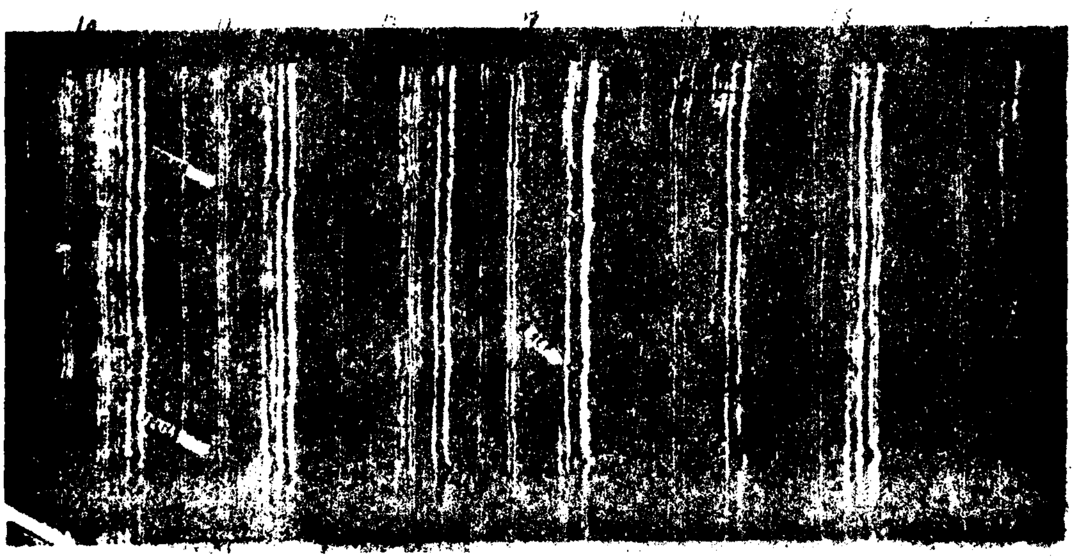
Anomalies listed are probably related to the open splices in the BFG information system. An inclusion is marked in channel 15. This may also be a separation. It extends to channel 16. Also in channel 10 there are two additional anomalies, one of which could be a separation, and the other of which could be either a separation, a missing ply or the liner blister noted in the information submitted with the tire.

N 88 7901 - This retreaded tire was reported in the submitted information to contain separations and four heavy splices. Ultrasound identified five separations and four anomalous splice areas. In addition, one anomaly appeared in channel 4 which could not be identified.

N 88 7902 - This was a retreaded tire marked RI. The information received with the tire indicated 4 separations. Analysis of ultrasonic data showed six areas having possible separations and two areas in which splices could be questioned. In three places the ultrasonic data and the data furnished with the tire agree.

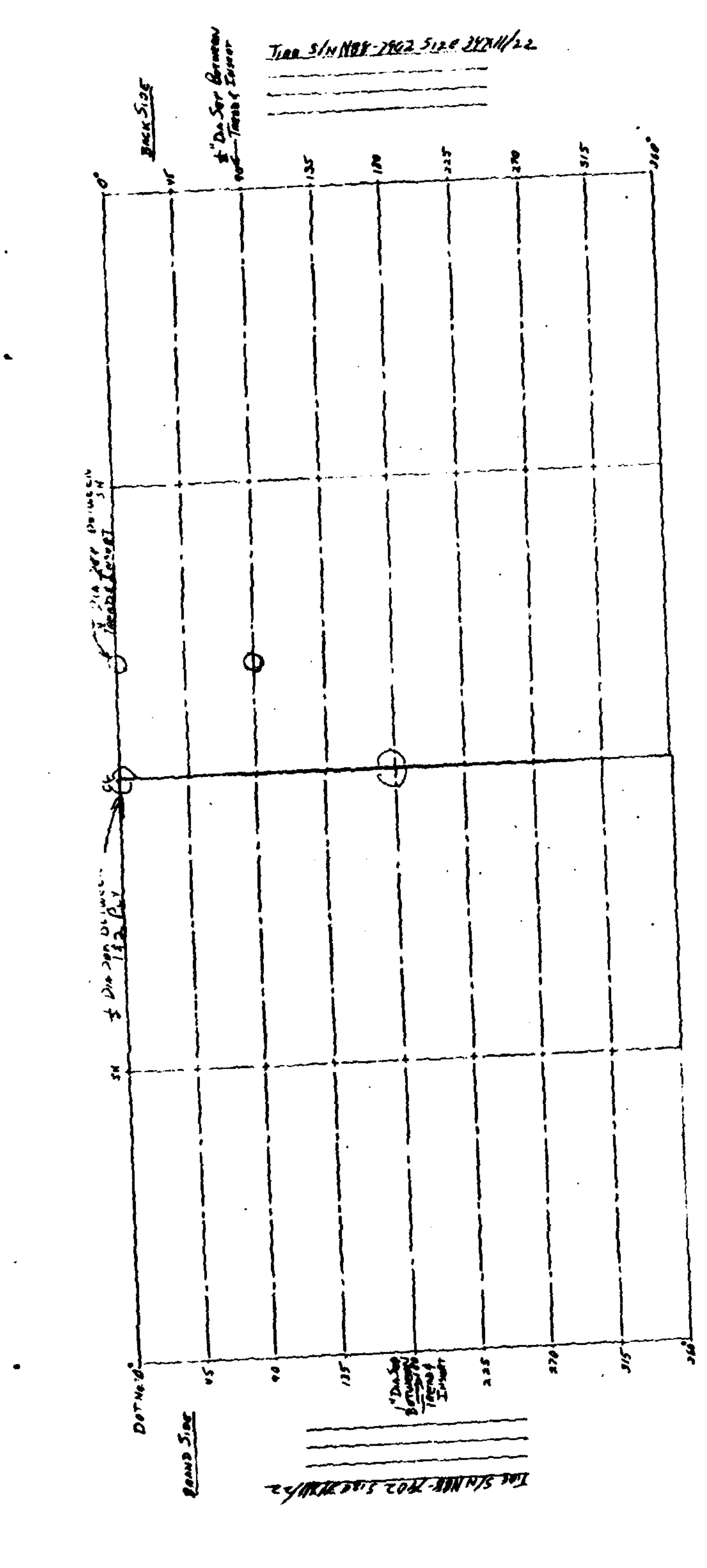

Tire S/N N88-7901 Size 24x11/32
Brand Side
Back Side
Dot No. 0°
1" Dia Sep Under #2 F.S.
SH
CL
1" Splice #3 Insert
1" Splice #1 Insert
1" Splice #2 Insert
1½" Liner Splice
Buster In Splice
1" Dia Sep Between 9/10 Ply
0°
45
90
135
180
225
270
315
360°

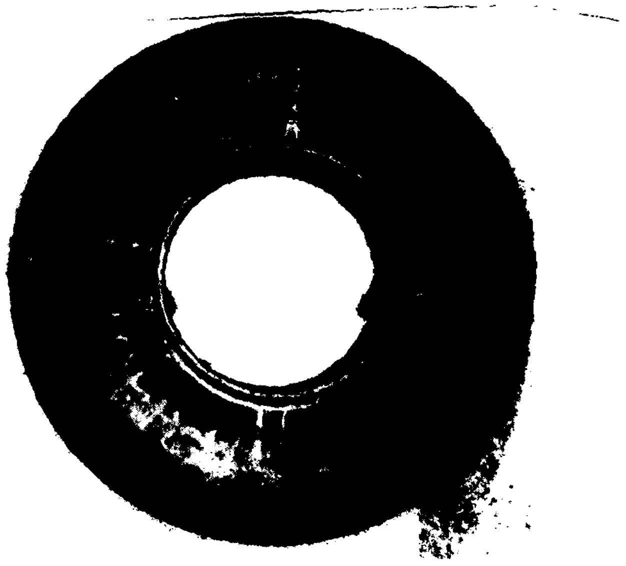
N88-7901

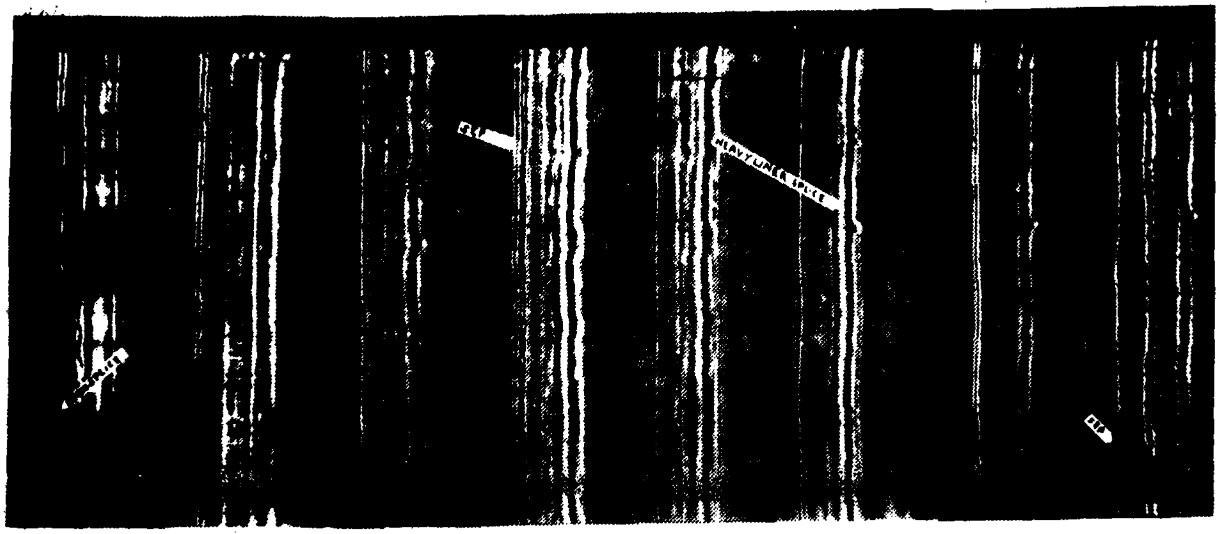


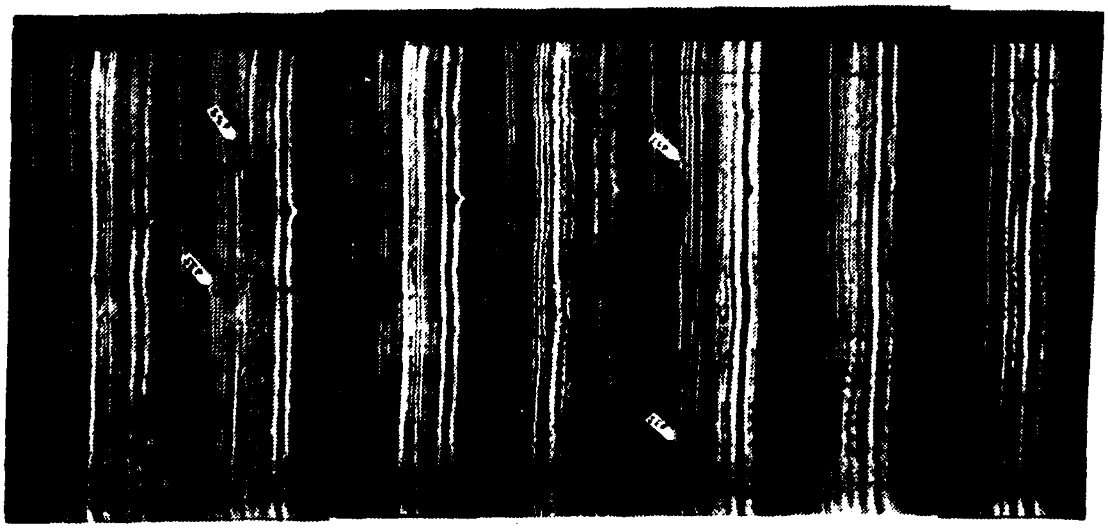
N38-7901

N88-7902






HEAVY LINER SPLICE



5. CONCLUSIONS

Table 1 is a summary of the findings from the analysis of ultrasonic data, and a comparison with the information provided with the tires. In the section marked coincidence, the number of separations was counted and other anomalies were counted,listed and compared with the information from BF Goodrich. In order for the ultrasonic data to agree, the information as described in ultrasonic analysis had to agree with the flaw data description and its location also had to coincide. This coincidence occurred for separations in 26 out of 30 instances ,or 87% coincidence. The aggregate total of separations and other anomalies was 92 percent. The side opposite the serial number of each tire was not scanned by ultrasound. If the flaw data for this area of these tires is neglected, ultrasound would have found all separations.

Moreover there were a number of characteristics found in the ultrasonic analysis which did not appear in the information received with the tires, such as heavy or light spots in the tread and disturbed splice areas. These conditions are not capable of being detected by other methods. Also the origin of separations can be differentiated by ultrasound where this is difficult to accomplish by other means.

Equipment Characteristics

In spite of the fact that the equipment used was designed specifically for passenger-car tires, it performed satisfactorily for aircraft tires. The technique can be considered valid in this application. No further research efforts are required, but additional routine engineering development is necessary to build a system completely responsive to the needs of aircraft tire inspection.

There are no technical barriers to inspecting tires up to 52" x 20"/23 ply. Specialized handling equipment should be developed which is compatible with handling equipment now in use in tire maintenance facilities. The use of ultrasound in flaw detection

	FLAWS CONSIDERED		B.F. GOODRICH DATA		POINT FOR POINT COINCIDENCE	
	SEPS.	OTHER	SEPS.	OTHER	AGREE SEPS.	AGREE OTHER
N887902	6	2	4	0	4 of 4	0
N887901	5	4	7	4	5 of 7	4 of 4
N887900	7	6	8	3	7 of 8	3 of 3
N887899	4	1	6	0	4 of 6	0
N880773 #6	2	2	4	4	2 of 2	4 of 4
N660773 #4	1	1	3	2	1 of 1	2 of 2
N660773 #3	3	2	3	3	2 of 2	3 of 3
N660773 #2	1	11	0	4	0	4 of 4
TOTAL	29	29	35	20	26 of 30	20 of 20
					87%	100 %

AGGREGATE TOTAL 92%

could easily become routine.

Interpetation of Data and Training

The data presented in this report is representative of the class of display presently available. Once the types of anomalies considered important in aircraft tires are identified, it is a relatively simple matter to train personnel to analyze the displays to find these anomalies. In the case of passenger tires a junior technician can be trained in about four days to detect the twelve characteristics which are considered serious. He can then analyze data at the rate of about 40 tires per day. It is reasonable to expect that a technician could be trained to analyze aircraft tire data in the same time and to operate at the same rate.

Automatic Analysis

All of the anomalies identified in the aircraft tire data can be electrically analyzed. A demonstration of this was not possible within the context of this study, however there are no fundamental problems. The penalty paid for additional information processing is additional initial cost of the equipment. For passenger tires the estimated cost to interface to a satisfactory computer data bank for comparison of tire data is about $60,000. Most of the circuitry to provide the necessary signal processing and analysis is in the basic equipment. Experience has taught, however, that it is necessary to identify, classify and quantify flaws before automatic processing can begin.

System Costs

The research and devleopment costs to build the ultrasonic inspection system as it now exists at TSC was approximately $200,000; annual maintenance costs have been approximately $20,000 for the past three years.

Direct operating costs include one man full-time and normal industrial services:

30 amp 220 VAC
water, city tap
Air at 130 psi.